THE BUILDING OF AN ISLAND

JOHN T. QUIN, F.R.G.S.

St Croix D. W. I.
6 February 1908

Dr Arthur Hollick
New York

Dear Sir

I am taking the liberty to send you by present post a copy of a book on the geology of our island, which I got out last year, and beg your acceptance of the copy.

You may perhaps remember that I forwarded you some fossils in May last year, under the belief that they were of Vegetable origin, and you were kind enough to examine t

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R.G.S. The Author, Christiansted,

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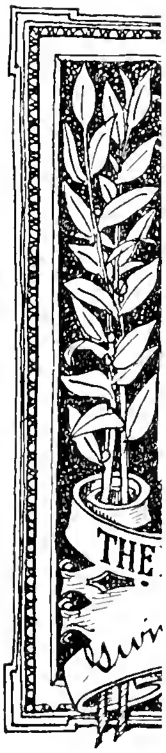
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and report that they were not such; but of animal origin.×

You were further kind enough to say that you would send the specimens to Professor A. W. Grabau at Columbia University.

I need hardly say that it would be a great pleasure to me to have the Professor's opinion of these fossils.

You will see that in my book the error is acknowledged. I did not feel justified in mentioning your name, as I had no authority to do so; but I am very grateful to you, all the same.

Very truly yours

John T. Quin

× See p. 38.

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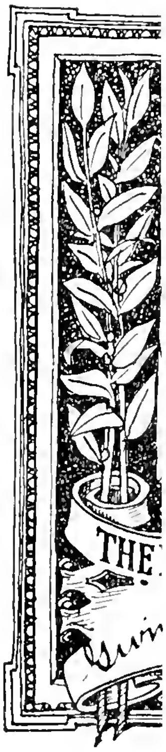
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The Building of an Island, being a Sketch of the Geological Structure of the Danish West Indian Island of St. Croix, or Santa Cruz. By John T. Quin, F.R.G.S. The Author, Christiansted, St. Croix. 1907. 4to.

The twelfth or concluding chapter of the work under consideration begins as follows:

> While it seems desirable, in entering on the study of the geological formations of our island, to begin with the younger set of rocks and trace the story backwards, it may be instructive, in summarizing the results of our observations, to take the opposite course, and, as far as possible, note leading events and conditions in their natural sequence.
>
> As a preliminary, we must remember that the crystalline structure prevalent in our older formation has been induced in the strata since the materials of which they are composed were deposited, and similarly that the dikes of igneous rock which we find cutting them through have been intruded so that in the first instance we have to confine our thoughts simply to their deposition.

While thanking the author for the valuable suggestion that the components of a rock were on hand when and where that rock was formed, we, and probably a great many others, had been bold enough to suppose this fact without first consulting him. He is manifestly a schoolmaster, or, as modern American terminology has it, an "educator," and he attempts in twelve dismal chapters and with the aid of diagrams and plans, together with a map as recent as 1856, to "educate" us to a vague conception of the building or formation of the island of St. Croix in the Danish West Indies. The above quotation gives an idea of his average style, but we shall not attempt to give specimens of the pedantry displayed in almost every part of the book. It is difficult to conceive whether that book is written for a well-informed public or for a primary school. If for the former, the childish object lessons, as in the first chapter, the tiresome and almost offensive explanation of the cause why lime-rock effervesces in muriatic acid and clay does not, the interesting statement that soils are classed among rocks, and the almost endless dissertation on Foraminiferæ and the like are wholly superfluous; if for children, the bulk of the text has too many pretensions to being technical.

We look in vain for terse, logical conclusions. All we can discern is, that the author favours the opinion that there may have been two successive formations of the island, one, possibly anterior of the Cretaceous period and followed by submersion; then again, slow upheavals and subsequent deposits so as to form another dry surface. The latter "perhaps" at the time of the chalk formation. Trap dikes indicate that the volcanic forces have, to a limited extent, risen to the degree of eruption on the surface. We do not attempt to penetrate any further into the intricacies of the book, wishing the reader much patience in his endeavours to peruse it. The illustrations are mostly quite commendable. A. F. B.

1908

Dr. Arthur Hollick

with respectful compliments
of the author.

THE BUILDING OF AN ISLAND,

BEING A SKETCH

OF THE GEOLOGICAL STRUCTURE OF THE DANISH WEST INDIAN ISLAND OF ST. CROIX, OR SANTA CRUZ.

BY

JOHN T. QUIN, F.R.G.S.

Royal Medalist, Denmark; lately Inspector of Schools in the Danish West Indies.

1907

Printed in New York by Chauncey Holt,
and Published by the Author in Christiansted, St. Croix.

PREFACE.

THE following pages contain the results of the writer's study of the geological structure of St. Croix from time to time through a long period of residence in the island. Had these results been stated for the information of the professional or amateur geologist they could have been described in much fewer words than are here given to them—the map with two or three pages of notes would have been sufficient; but they have been here recorded with quite another purpose. It has been the aim of the writer to open up for the reader, whether resident or visitor, to whom the subject is new, or only slightly known, a field of great and varied interest.

There are doubtless many people who find it easy to understand that the vegetation of an island, its trees, shrubs and herbs with their flowers, may constitute a very attractive subject, and that the same may be true of its insects or its shells; but it has, perhaps, never even occurred to them that the study of the solid structure of the island can possess any great attraction. They have never asked themselves such questions as: What is beneath our feet? What is it made of? How came it there? Is it a solid mass merely, or does it show arrangement of parts, and if so, of what parts, and how are those arranged? It is hoped by the writer that some at least of those who read these pages may come to see that such questions as these can be answered, and that the observations which we make in order to answer them lead to others, also of a very attractive character.

It has been truly said that a great part of an educator's success depends on his ability to rouse the spirit of inquiry in his pupils. They will then work for themselves, and the knowledge they acquire in this way is not likely to be forgotten. It takes little reflection to see that it is the spirit of inquiry in mankind to which we owe all those great discoveries and inventions that have placed the present generation in the advanced position which it occupies in regard to the use it is able to make of the various powers of Nature. A fragment of amber rubbed on a piece of cloth attracts light straws, etc. Why? The continued pressure of this "Why" at every step of the inquiry has led to all the marvels of electrical science as we now have it, and who can tell how far it may yet lead us? Watt looks at the rising lid of the steaming kettle, asks Why? and we get a revolution in the building of steam-engines. Torricelli sees that a suction pump will not lift water higher than about thirty feet; he asks Why? and we get the barometer. And so with every great discovery and invention that has been given to the world, it is the result of the activity of the inquiring mind of man. For the mass of us there will, of course, be no results of our inquiries which can affect the comfort and happiness of any large portion of our fellow men, but they can very greatly affect our own personal comfort and happiness. The habit of inquiry leads to that pleasant occupation of the mind which tends to raise its tone, which continually gives matter for study and reflection, renders *ennui* impossible, and makes such questions as, Is life worth living? absurd.

Such reflections as these suggest that it might be well to try to induce the advanced pupils in our schools to observe for themselves the common things around them, and to

make the inquiries which will naturally follow. Why is one pebble smooth and round while a second is smooth but angular and a third is both angular and rough? Why is a fourth marked with streaks, a fifth with spots, and so on? Such questions would no doubt in the first instance have to be answered by the teacher, but they should always be answered when possible by referring the pupil to a spot where he will see the answer demonstrated. By-and-by he will learn to find answers for himself.

This leads to the remark that the reader of these pages should in no case be satisfied with merely reading the descriptions and conclusions of the writer, but should as far as possible visit the places named and see for himself. He should go armed with a lens and a pocket compass, and verify the writer's observations, or correct them, as the case may be. In this way he will find new points continually cropping up, and the range of his inquiry continually increasing. By-and-by he will find that in the study of even this little island he has gained some insight into the ways in which mountains have been formed and lifted, the way plains have been levelled and valleys carved out, not only here and in other islands, but also in those greater lands which occupy a large part of the surface of our globe. As an introduction to an intelligent study of physical geography, the local study will thus become invaluable, and if these pages should lead the reader to undertake such local study, they will have served the purpose for which they are intended.

NOTES ON THE MAP.

The map is reduced to half size, linear measurement, from the chart of Santa Cruz, drawn after a survey by Mr. John Parsons in 1856, and published at the Hydrographic Office of the British Admiralty, London.

It is hoped that the present map will be found fairly accurate; but the reader who wishes to follow up the observations noted in the following pages should procure a copy of the above-mentioned chart or of one published at the Hydrographic Office, Washington, on which to note such facts as he may learn about the character and slope of the strata, etc.

The full names of the estates and other points indicated by initials on the map are printed in columns corresponding with the section in which the places are respectively found. They are also arranged, as far as possible, in a descending order answering to the positions of the places.

The reader is advised not to take any notice of the red and blue lines which cross the map until he has read the account of them given in the text. They are mostly ruled lines, but it must not be supposed that the bends in the strata indicated by them are equally straight, and it may be that further detailed examination of the rocks may make some modifications necessary.

H B—Ham's Bay.
N S—North Side.
B B—Butler's Bay,
S H—Sprat Hall.

H Bl—Ham's Bluff.
S G—Spring Garden.
A—Annaly.
M S—Mt. Stewart.
P—Punch. O—Oxford.
O G—Orange Grove.
M—Montpellier.
T F—Two Friends.
J H—Jolly Hill.
B G—Beck's Grove.
A—Allandale.
H—Hope.

N S—North Star.
C B—Cane Bay.
La V—La Vallée.
P—Prosperity.
C—Canaan.
M E—Mt. Eagle.
B M—Blue Mountain.
F—Fountain.
M P C—Mt. Pleasant (Colquohoun).
R—River.
U L—Upper Love.
G P—Grove Place.
L L—Lower Love.

R T—Rust op Twist.
B B—Baron's Bluff.
S R—Salt River.
L H—Lebanon Hill.
W—Windsor.
U C—Upper Concordia.
M S—Morning Star.
M—Montpellier.
G—Glynn.
R—Rattan.
M B—Mon Bijou.
M—Moravian Station. (Friedensfeld).
B E—Bonne Esperance.
S H—Sion Hill.
M F—Mary's Fancy.

S R P—Salt River Point.
J F—Judith's Fancy.
S J—St. John's.
L P—La Princesse.
Lt P—Little Princess.
L R—Long Reef.
O G—Orange Grove.
A H—Alder's Hvile.
S H—Sion Hill.
C H—Constitution Hill,
B M—Bulow's Minde.
H H—Hermon Hill,

P—Prosperity.
L G—La Grange.
Fr—Frederiksted.
S P—Sandy Point.

C V—Cane Valley,
W F—Wheel of Fortune.
S G H—St. George's Hill.
L C—Lower Concordia.
W—Whim.
C—Carlton.
Cn—Cane.
H R—Hannah's Rest.
C—Camporico.
G H—Good Hope.
W B—White's Bay.
L P—Long Point.

—Castle Bourke
Pl—Plessens.
M—Mountain.
D S—Diamond School.
M—Mt. Pleasant.
A—Adventure.
G G—Golden Grove Residence.
P—Paradise.
N B—Negro Bay.
W D—William's Delight
M B—Manning's Bay.
E—Enfield.
B H—Betty's Hope.

B—Bethlehem.
F—Fredensborg.
L R—La Reine.
S—Slob.
S H—Strawberry Hill.
D—Diamond and Ruby
K H—King's Hill.
O M—Old Mill.
B S—Barren Spot.
S T—Spanish Town.
B—Blessing.
H—Hope.
J—Jerusalem.
A—Anguilla.
K L—Krause Lagoon.
K P—Krause Point.
L R—Long Reef.

S F—Sion Farm.
P R S—Peter's Rest School
C C—Castle Coakley.
P R—Peter's Rest.
A H—Anna's Hope.
G E—Grange.
C R—Catherine's Rest.
W R—Work and Rest.
J—Jerusalem.
C G—Cane Garden.
G—Granard.
D K—Diamond Keturah.
W P—Waiter's Point.

A—Fort Augusta.
h—Christiansted.
h L—Christiansted Lagoon.
—The Kay.
—Shoys.
—Bœtzburg.
H—Lowry Hill.
P—St. Peter's.

G K—Green Kay Islet and Estate.
P P—Pull Point.
S G—South Gate.
E H—Easthill School.
C B—Coakley Bay.
S—Solitude.

H—Bugby Hole.
H—Corn Hill
—Munster.
—Springs.
—Fareham.
—Longford.

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S—Sight.
S F—Sally's Fancy
M W—Mt Washington Estate.
P—Petronella.
G P—Great Pond.
C G—Cotton Grove.

B I—Buck Island.
C V—Cotton Valley.
M C—Madam Carty.
T H—Turner's Hole.
G T B—Grape Tree Bay

E P—East Point.
G H—Goat Hills.

CONTENTS.

CHAPTER I.

INTRODUCTORY.

The Island, its Position and Size.

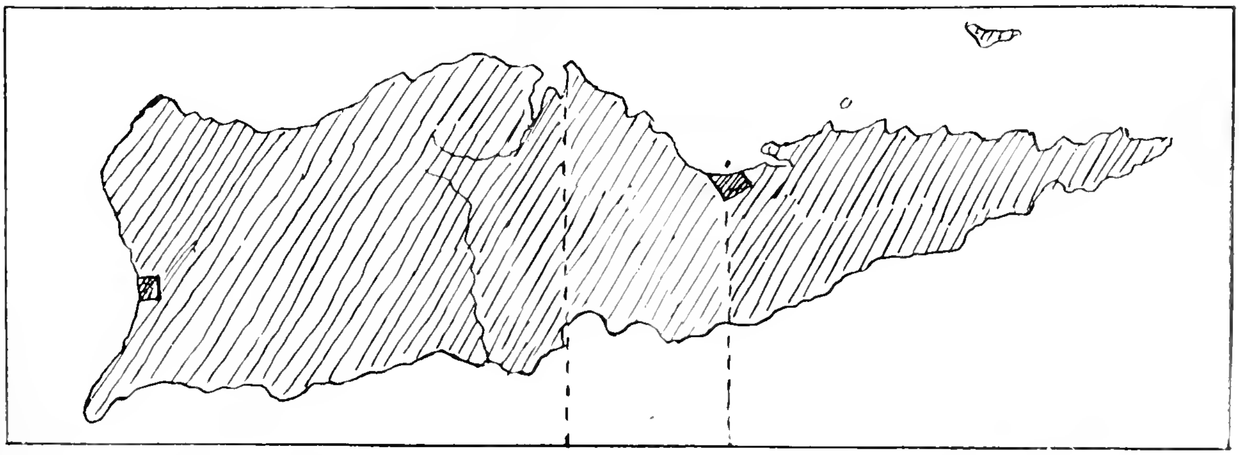
The Danish West Indian island of St. Croix, or Santa Cruz, lies in the northeast corner of the Caribbean Sea. It has an elongated form, stretching from east-northeast to west-southwest and measures a trifle over 22 English miles in length, while its greatest breadth is only about six miles. Its area is about 80 English sq. miles, say three fourths the size of the Isle of Wight or a little over one third of the size of Bornholm.

It is the largest of the three Danish West Indian Islands, St. Thomas containing about 23 English sq. miles and St. John 20 miles. Comparing it with a few of the smaller British islands in these seas we find that it is about half the size of Barbadoes, three fourths the size of Antigua and a little over the size of St. Kitts.

The Submarine Santa Cruz.

When we examine a chart of the island shewing the soundings around its shores, we find that while it rises rather abruptly from the sea on the northwest and west, it is bordered on all other sides by an extensive bank, on which the depth of water only at a few points along the edges exceeds 20 fathoms, and is commonly very much less, and from which the descent into the deep sea is steep, though not so steep as in the northwest. This bank, which on the map is enclosed by the 100 fathom line, and is at least as extensive as the island itself, may be looked upon as a sort of submarine Santa Cruz, and the study of it, as we shall see later, throws a flood of light on the story of the building up of the island.

FORM OF THE ISLAND.



The Western Oblong. The Neck. The Eastern [illegible]

THE ISLAND'S OUTLINE.

When we now examine the form of the island itself, we see at once that it may be regarded as consisting of three parts, namely, an oblong portion to the west, a narrow triangle to the east, and in the middle a neck by which the two other parts are united.

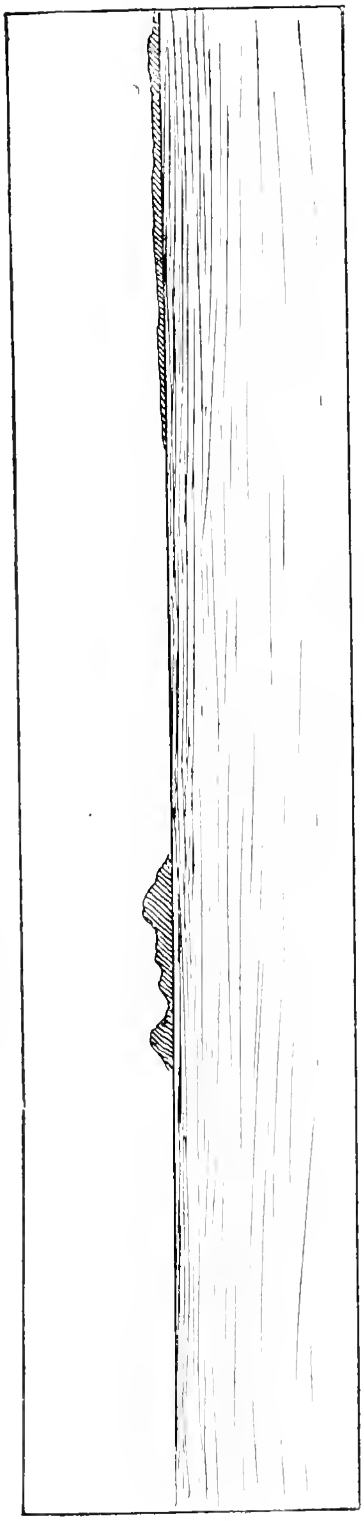
This peculiarity of outline should be carefully noted, for we shall shortly find that, simple and obvious as it is, it has a most intimate connection with the story to be studied. We may observe in passing that the town of Christiansted stands on the northern shore of the island at the narrowest part of the neck just mentioned, while the town of Frederiksted stands on the western shore.

THE ISLAND'S SURFACE.—THE "WESTERN OBLONG."

From this general view of the outline of the island we may proceed to consider its surface. Referring to the map, and confining our attention in the first place to the *western oblong*, we notice that the northern part of this oblong is covered with hills, while its southern part, stretching to the sea, is a plain, broken in its eastern part only by a few low hills. Leaving for the present this plain, which also extends itself through the eastern part of the oblong and as a narrow valley reaches the northern shore, we may give our attention to the northern hills. The whole chain of these northern hills is naturally divided into three parts. The first of these to be noticed is a short ridge lying northwest and southeast and containing the chief elevations of the island, namely, *Blue Mountain* (1090 ft.) at its southern end and *Mount Eagle* (1164 ft.) at its northern end. This ridge is the most conspicuous feature of the island. From the wharf at St. Thomas (40 miles away to the north), it is almost the only part of Santa Cruz that is visible. Viewed from the central part of Santa Cruz itself it is also a conspicuous object. That this ridge is an important feature of the island's geography may be further inferred from the fact that the drainage of the valley on its eastern side is turned to the northeast and finally flows out, by the creek known as Salt River, on the *northern shore* of the island, while the drainage of the valley on the western side is turned southwards and flows out on the *southern shore*.

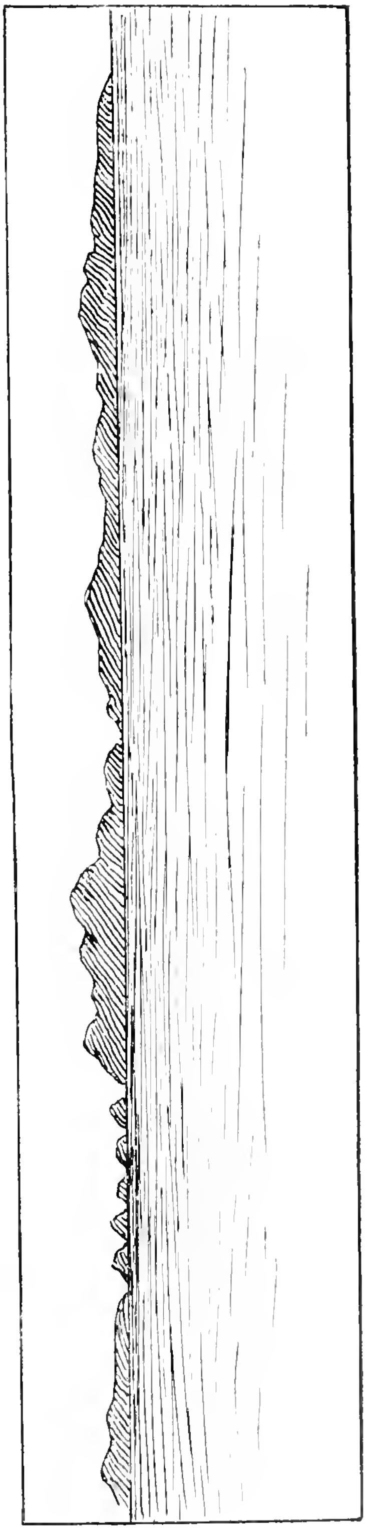
The above ridge is connected by lower hills with a range to the eastward known as the Salt River Hills, the highest point of which (towards its east end) is 872 ft. above the sea-level. The spurs of this range press on the sea shore, along which a picturesque road is carried to reach the valley which in part marks off the range from the Mt. Eagle Ridge, or, more accurately speaking, from a spur of that ridge.

On the west side of the Mt. Eagle Ridge low hills connect it with an extensive group, which must be regarded rather as a block of hills than a range. This block of hills fills up the northwestern corner of the island, and has on its eastern edge some elevations of over 600 ft., while towards the west are Mt. Washington, 807 ft., and a hill east of Frederiksted, 850 ft.



Mt. Eagle Ridge.

Santa Cruz as seen from the wharf at St. Thomas.



Northwestern Hills

Mt. Eagle Ridge.

Salt River Hills.

The northern hills of Santa Cruz seen from an elevation of about 70 feet, St. Thomas.

The hills of the north side of the island (or, on the north side of the *western oblong*), though all connected by lower elevations, may then be regarded as consisting of three parts: 1—The Mount Eagle Ridge, 2—The Salt River Hills to the east of that ridge, and, 3—The much more important northwestern block of hills to the west of it.

The Eastern Triangle.

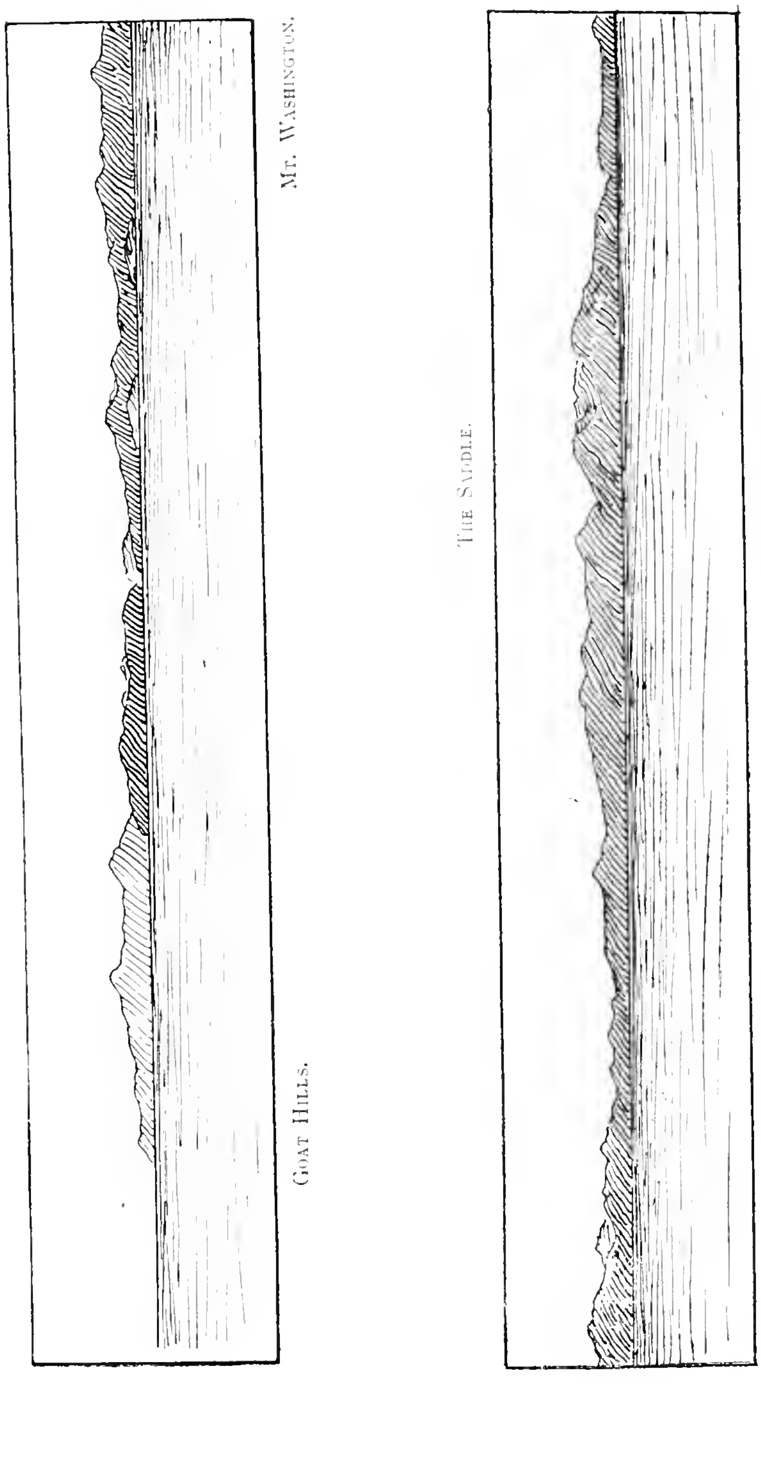
If we now leave the *western oblong* and cross over the intervening *neck* to the *eastern triangle* (known as the East End), we find the central strip of that triangle to be occupied by a range of hills, not so high as those of the northwest, but still reaching in several places a height of over 800 ft. The range is continuous, yet, like the hills of the northern chain, it is naturally divided into three parts. This division is plain enough when the range is seen from the sea, and becomes very striking when it is viewed from the top of Blue Mountain, from which elevated point it does not look like a continuous range at all, but appears to be three clumps of hills, one behind the other.

The three groups into which the eastern range of hills is seen to be divided, are, first the *Christiansted Hills*, next the *Mt. Washington Hills*, and lastly, the small *Goat Hills* group at the eastern extremity of the island.

The Christiansted group is slit across from north to south by a narrow valley, which forms a locally well-known landmark for sailors and is called among them "*The Saddle*." This valley, which in its highest point rises to about 400 feet, has on its western side a peak of 855 ft. in height (Signal Hill, looking down on the town), and on its eastern side several peaks of between seven and eight hundred feet. The height of the group decreases eastwards, and it is joined to the next group by low hills of about 300 feet, while it is well marked off from that group by the small plains of "Southgate" on the north side and "Great Pond" on the south, each having a large pond near the shore.

The Mt. Washington group has a peak of 860 ft. with others not much less, and sinks gradually to 400 ft. at its eastern end, where it is divided by a valley crossing a narrow neck of the island at "Grape Tree Bay" from the small "Goat Hills" group, the highest point of which reaches 660 feet.

Having now seen that there are two principal hill ranges on the island, namely, those of the *western oblong* and those of the *eastern triangle*, we may next look at them in their relation to each other. After noticing, as we have already done, that they are parted from each other by what we have called an *intervening neck*, we notice that they are not in the same straight line; yet in their general direction are parallel to each other, so that, if continued, they would run side by side, with their crests about three and a half English miles apart. The eastern range ends rather abruptly at Christiansted. The northern range stops in like manner at Salt River, but is represented farther east by a few low hills along the northwest shore of the "neck" and by the islet called "*Buck Island*" (summit 340 ft. above sea-level), and the submarine bank from which that islet rises.

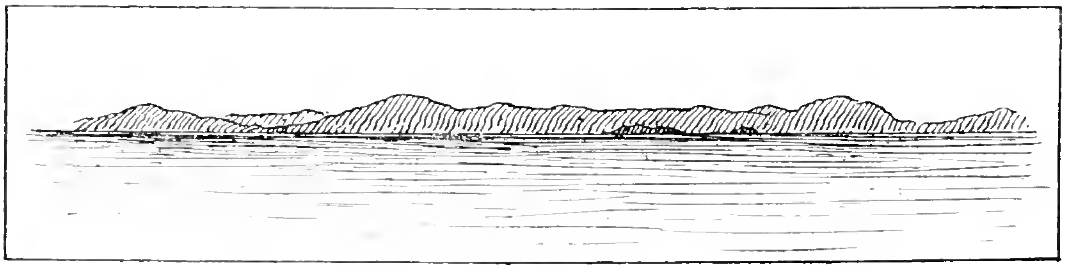


Eastern Range as seen from the sea off north coast

The Intervening Neck.

We may now leave for the present the two divisions of the Island which have been described as the *western oblong* and the *eastern triangle* and turn our attention to the *intervening neck*. We see from the map that this neck is narrowest near Christiansted, where it joins the eastern triangle. It is there not more than three miles wide, but it broadens westwards, for the coast from Christiansted does not follow the general trend of the northern shore, but runs northwest to Salt River Point, a distance of about four English miles. Along this strip of shore lies a beautiful little plain which, from the names of the sugar estates which occupy it, may be called the "*Princess*" plain. At the back of this plain and lying parallel with the shore is a range of hills having as its highest points heights of between 500 and 600 feet. This little range forms the northern edge of an undulating tract of country which slopes gradually down from it towards the island's southern shore. This sloping tract, which may appropriately be called the *Central Slope*, is separated by valleys on either hand from the higher hill ranges to the east and to the northwest of it. The sketch shows how the hills forming its northeastern edge and looking over the Princess plain, look in outline as seen from the sea. This is the only part of the island where the sugar cultivation comes over, at the present day, to the north shore. It is thus the most beautiful part of the north coast, and for us in regard to our present purpose it has very great interest, for it is with this *Central Slope* that we shall presently begin our study of the island's structure. Turning for a moment to this slope as depicted on the map, we see that on its eastern side it is scored by valleys that run to the southwest while on its western side the valleys which furrow it run to the south. The plain which separates it from the eastern range of hills is only a small one; but that which divides it from the northern hills widens rapidly southwards and opens into the wide plain south of those hills, forming with it the richest part of the island. A few low hills along the south shore are, as we shall see later, of the same general structural character as the central hilly slope, but are separated from it by a valley reaching the southern shore, namely, past the estates La Reine, Barren Spot and Hope.

Fig. 6.



THE ROCKS OF THE ISLAND.

The above sketch of the geography of the island may perhaps be sufficient as an introduction to our study of its structure; further details may be noticed as we proceed.

The surface described is clothed nearly everywhere with vegetation, which to a great extent hides the soil. In the cultivated parts of the island, however, we may often see large areas of the soil exposed, and in the uncultivated portions the sides of the watercourses and the cuts made by the small rills running down the hillsides also afford us peeps at the soil and the subsoil. When now we take advantage of these various opportunities, and examine the soils in different parts of the island we soon see that they differ very considerably from each other, and if we examine the stones found in them we find that they also vary a good deal. Sometimes, moreover, we get to see, in road-cuttings and elsewhere, what lies *below the soil*, that is to say we get to see some of the substances which make up the solid mass of our island, and we soon perceive that they too show noticeable differences. In some cases they differ only slightly from each other and we may put them in the same class; but in other cases they differ so much that we have to put them in separate classes. If we take our specimens from any quarry or "gravel pit" in the East End or from the hills of the north and west we shall find that they generally bear a great resemblance to each other; they most frequently have a rusty look, especially those that have been long exposed to the weather. These sometimes crumble to pieces and are then often spoken of as "rotten rock"; but if we go deeper into the rock in the quarry and break a piece through, we find that it is hard and crystalline and most often has a bluish or grey colour. These colours are also often shown very plainly on the roads where the rock has been worn by the traffic, and in a still more striking way in the pieces that have been broken out of the cliffs by the force of the waves and have afterwards been rolled about and rounded on the sea beach. Hence the common local name for the hard rock from which these pebbles and boulders have been formed is "blue-beach." With some interesting and important exceptions to be noted later, this is the rock which we shall find from Christiansted eastwards, throughout the *eastern triangle* and also through the northwest district of the island; but if we take our specimens from the *neck* which intervenes between those two parts, or, to speak more accurately, from the *Central Slope*, we shall find something very different. Here the rocks are mostly white or creamy in colour. Sometimes they are soft and are known as marls, sometimes they are hard and are called limestones, or locally, "marl-stones." In either case it is easy to see that they must be placed in a quite separate class from the blue-beach rocks.

Before proceeding further, however, it should be noted that the word "rock" is used by geologists in a peculiar sense. While in daily language a "rock" means a mass of *hard* stone, in geological language it means any mass of material that goes to make up the crust of our earth; hence beds of sand

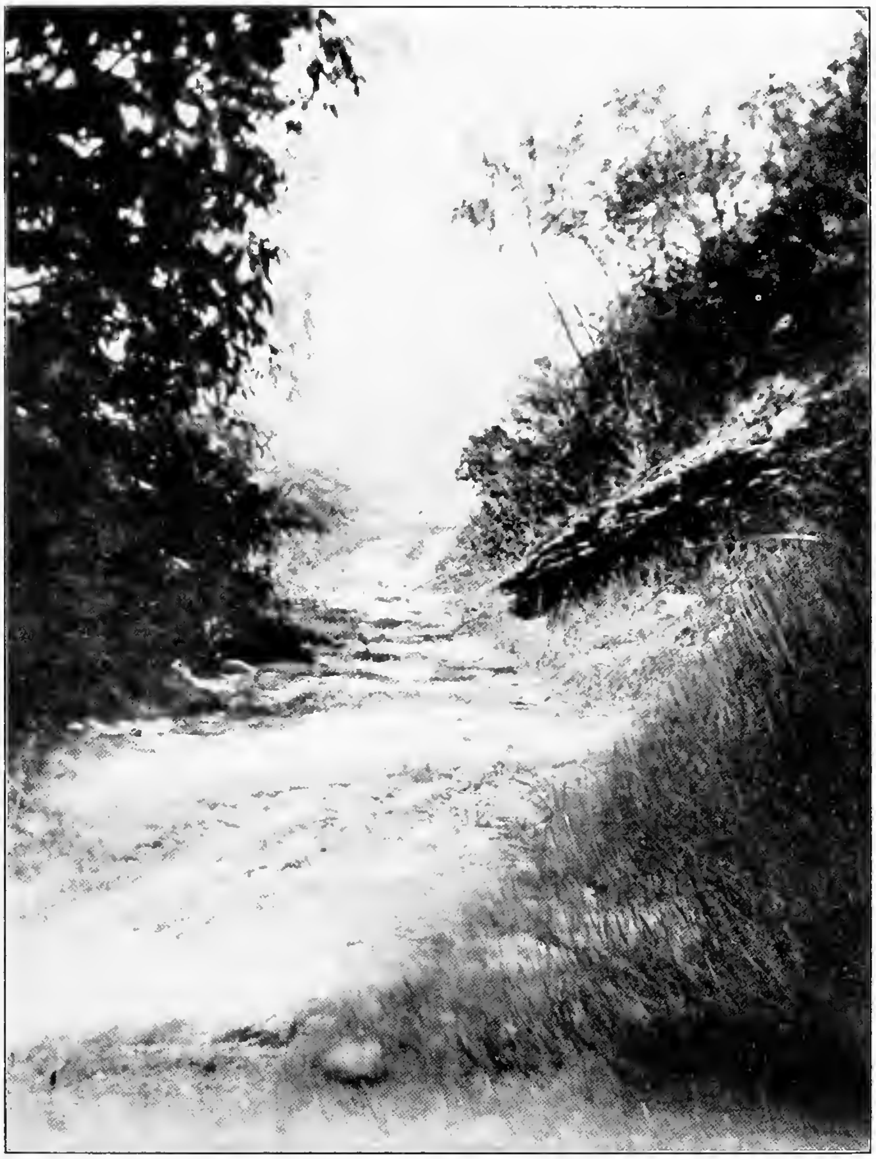
and clay and soft marls are included among rocks, as well as limestones, gritstones or granites. It is in this more general sense that the word is used in these chapters.

The Two Rock-Formations of the Island.

We find then in the island two great classes of rocks, those which belong to the "*blue-beach*" set, and those which belong to the *marls and limestones*.

That there is some essential difference between these two classes of rocks may be shewn in a very simple way. We take two glasses, each containing a little diluted muriatic or other acid, and into one of them we drop a "blue-beach" pebble, while into the other we drop a fragment of limestone, and we see that the limestone immediately begins to effervesce while the blue-beach remains nearly or entirely unmoved. What is the reason for this singular behaviour on the part of the limestone? It is that the stone is for the most part a combination of lime with carbonic acid gas and that the latter is released by the action of the acid and comes away in bubbles. The blue-beach pebble behaves differently because it is quite a different substance, being for the greater part a combination of the substances which make clay and quartz.

It is plain then that we have two great classes of rocks in the island, and we shall see later that, although the histories of these two great divisions are in some respects alike, their modes of origin are for the most part very different.



Stratified Marl Rocks, Anna's Hope.

CHAPTER II.

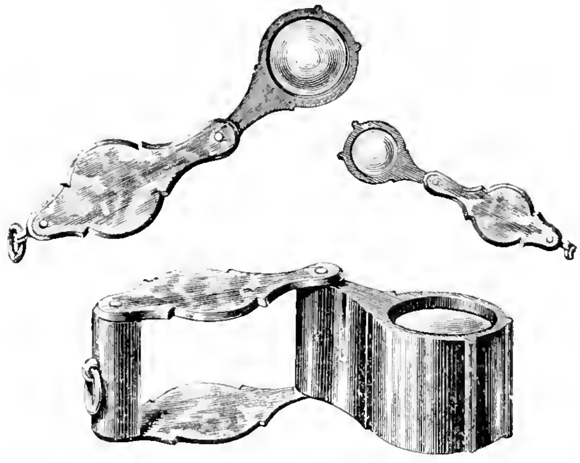
The Limestone and Marl Formation in the Central Slope.

The *Central Slope* of the island is occupied by the limestone and marl formation, which also stretches along the southwestern shore to the west end of the island. We shall see later that it is the younger of the two great formations which make up the island, namely, the *marl* and the "*blue-beach*," and that it rests upon the latter. The soil over the marl formation sometimes, and especially on the hillslopes, has a whitish appearance, and very often contains numerous stones broken out of the formation in a way to be studied later.

The formation may be examined wherever it has been broken into, either naturally or artificially, as, for instance, artificially in road-cuttings and quarries, and naturally in sea-cliffs, watercourses and the like. We begin our study with a road-cutting at Anna's Hope estate, which is particularly suitable because it is easily accessible from Christiansted. Here the road is cut in the hillside, which gives us an opportunity to learn of what stuff the hill is built up. If the study is quite new to us, the first thing which will strike us will probably be that the rocks shewn at the roadside are arranged in layers, and the question will arise, how is that to be accounted for? Whatever their origin there can be no mistake about the fact of the existence of these layers, some of which form at this spot, as shewn in the accompanying photograph, natural steps in a path cut into the hillside and leading up to the estate residence. A further examination of the layers shows that some are softer than others, so that the weather acting on them wears them back and leaves the harder ones prominent. To proceed further, we ought to have a pocket lens* with us, and if we then break off a small piece

* A useful lens can be had from any optician at a cost of from two to five shillings; but if the reader is willing to spend something more on this most valuable little instrument, he is recommended to procure one of the platyscopic lenses made by Mr. John Browning of 78 Strand, London, and costing fifteen shillings. These lenses are made in three powers, and the cut shows the three forms, the most useful of which is the one of lowest power (the largest lens shewn in the cut), which multiplies the image of the object 10 diameters.

Fig. 7.



The present writer has used one of these lenses for many years and has found it a source of great enjoyment in the examination of the rocks and other natural objects in the island.

of the hard rock with a hammer or a handy stone, we shall probably find, on examining the broken surface with the lens, that there are minute shells in it, so small that they can be seen only with the help of the lens. These small shells are globular and are often filled with lime, so as to look like tiny balls. We perhaps think, as we look, that we should like to get them out of the rock so as to study them more easily; but this would be difficult. As we look around, however, we shall soon discover a hint that Nature has already done the work for us; for the weather, acting on parts of the rock, has reduced them to a fine powder, which we find lying on the hard ledges that have better resisted the "weathering" process.

Some of this powder we take home with us for examination, and we soon find that in its present form we can learn very little from it, a good deal of it being a fine dust which obscures the character of whatever harder grains the powder may contain, a fact which suggests that the first step is to wash away that fine dust. This is best done in a small glass saucer, preferably of a dark colour, or if of colourless glass the saucer may be placed over a dark fabric of some sort for the examination of the contents. A small quantity of the powder having been placed in the saucer, several washings will be necessary, the milky water being poured off each time, after which we shall see that we have a fine

NOTES ON THE SHELLS SKETCHED ON PLATE B.

a.—The globular shells are very abundant. Although found in the present oceans, they are not, as far as known to the writer, found in the shallow waters around St. Croix, but it is quite possible that they exist in the deeper waters outside the bank. They are generally one-fortieth of an inch or less in diameter.

b.—Commonly composed of a growth of three to five united balls.

c.—A pretty shell found rather abundantly at Bethlehem and elsewhere. The margins are translucent.

d-g.—Similar, but apparently distinct species. The largest, "*g*," is one-tenth of an inch in length. The kind "*d*" is abundant in one of the layers exposed at Anna's Hope.

h.—Found at Anna's Hope; the thirtieth of an inch in diameter.

i.—May be compared with the forms 2 and 3 below.

k.—May be compared with the form 8 below. Near the old mill, west of Barren Spot, a similar form with a convex base is abundant.

l.—Found at Anna's Hope; one-fifteenth of an inch in diameter.

m.—A minute pearly beauty from Anna's Hope, the sixtieth of an inch in diameter.

1.—One of the commonest species in the sea-sand, varying very much, apparently according to age. The dots in the upper part are intended to indicate the positions of some of the tiny chamberlets which form the entire shell, and in some cases are plainly seen, while in others they are hidden by the thickness of the porcelain-like shell. The whole shell is about the twentieth of an inch across.

2 and 3 are forms known as Miliolina (compare "*i*" above). No. 2 is a plain shell, but No. 3 is prettily ridged.

4.—A rare shell from Christiansted Harbour, the nearest to the straight kinds (compare "*d*" to "*g*" above) found by the writer in present-day sand.

5, 6, 7.—Coiled shells, which compare with "*h*" "*l*" and "*m*" above.

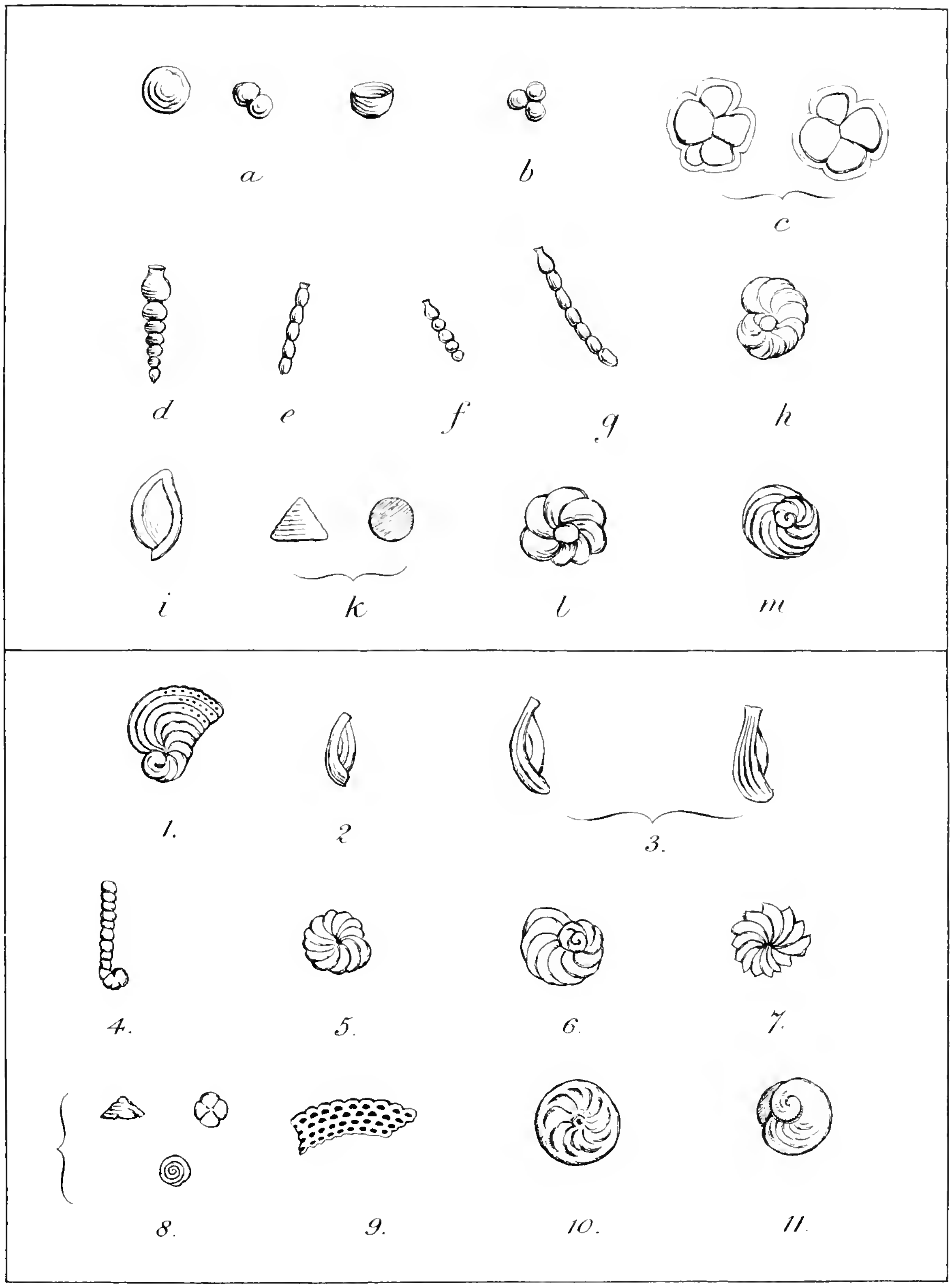
8.—Conical shell (compare "*k*" above).

9.—Fragment of a very beautiful flat shell, about the twentieth of an inch in diameter, which may not unfrequently be found alive adhering to the flat blades of the sea-grasses. The shell is so transparent that the chamberlets show as dark spaces on a white ground and the whole shell, as seen through the lens, resembles a beautiful piece of lace.

10.—A shining, porcelain shell, the curved lines in the sketch representing shadings in the shell.

11.—A rather common shell in the sand. It is about the thirtieth of an inch in diameter, and is built up of a great number of tiny chamberlets, which in slightly water-worn specimens show as minute holes crowding the surface.

B.



sand left in the bottom of the glass. Pouring a little clear water over it so as to cover it, we then examine this sand with our lens, and we get some interesting results. Among a multitude of sand grains, of various sizes, we shall find some, or perhaps many, of the round shells which we first saw in the solid rock, and we shall also from time to time meet with other forms, some of them very beautiful, others only odd; look, for example, at the beautiful coiled forms sketched on Plate B, and near them the curious jointed form resembling a sugar-cane.

These tiny shells are the remains of minute creatures called *Foraminifera*, and are found in most sea-sands. Hence, our examination of the marl rocks has already shown us that they were built up in the sea. By way of making the matter certain beyond all dispute, however, we may compare the forms which we get out of the rocks in the manner above described with the forms which we get from the bottom of the present sea. This comparison is made in the accompanying Plate, where the forms, roughly sketched in the upper half, are those of foraminiferous shells from our marl and limestone rocks, while the forms sketched in the lower part of the Plate are those of similar shells found in sand taken from the bottom of Christiansted Harbour or other shallow waters around our shores.

These minute shells in the rocks are found not at Anna's Hope only but at many other places on the island where the marl and limestone formation shows itself. The globular shells in particular are very abundant, and some of the others also in special localities, while others again are rare and have to be searched for. At all events, these interesting little shells are sufficiently spread through our marl formation to prove that it has in all parts the same origin, namely, that it has everywhere been built up, layer by layer, in the sea.

About the Foraminifera.

Having rendered us so important a service, these shells may, for a brief space, claim attention to their own history. They were once the tenements of living creatures, as their representatives in the present age now are in the oceans and seas known to us; and the study of the existing members of the family enables us to understand those which are extinct. Some species, indeed (the globular shells, for example), are both ancient and recent, being found as shell remains in the rocks and likewise as living creatures in the ocean.

Zoologists class all these minute animals as belonging to the Protozoa (first animals), so named on account of the apparent simplicity of their structure. Mainly they appear outwardly to be tiny pieces of living jelly, by which the shelly substance is deposited. By this deposition a small cell or chamber is formed. Some kinds never, or seldom, advance beyond this one-celled condition, but nearly all kinds go on adding new cells to the first. Some add the cells in a straight, or maybe slightly curved, line; but the majority of the species add the cells in a distinctly curved form, either a flat

coil or a spiral, that is to say, ascending like a screw; in a few species the extension is started on the circular plan and continued on the straight; some again add the cells in a succession of rings, one outside the other; and some add them alternately from side to side, suggesting the idea of their having been interwoven.

How do these little creatures live? Some kinds, those with the globular shells, for example, have the shells perforated with a great number of fine holes, through which long gelatinous threads are protruded from the body, and with their aid the animals catch the extremely minute particles of food by which they are nourished and from which they obtain the lime for their shells; with their aid, also, they move about in the seaweeds, among which they live. Most of the kinds, however, are not perforated in this way, but have apertures in the last or latest-formed cell, through which similar threads protrude; the other cells are connected with this one and with each other by a small hole, and this enables all parts of the tiny creature to remain in living connection. It is the possession of these minute holes through the cell-partitions that gives the whole family its name of FORAMINIFERA (bearers of small holes).

CONTRIBUTORS TO THE SEA-SAND OF THE SUBMARINE SANTA CRUZ.

We may now leave the consideration of these shells and push our inquiries a step farther. The foraminiferous shells found in the layers of the limestone rocks, prove for us that these layers have been built up from the sea bottom, but, except in regard to the generally small proportion which they themselves contribute, they do not show us *of what* the rocks have been built up.

The comparison which we have just made of the foraminiferous shells found in the rocks with those found in the sand of the great shallow that extends around a large portion of our island (the submarine Santa Cruz, as we have called it) suggests at once, however, a method of procedure: it suggests, namely, that by studying the story of the sand now forming along our shores and in our shallows, how it originates and how it may be converted, and sometimes actually is converted, into stone, we may find the solution of our problem.

The sand on the banks and in our harbours is often called *coral* sand, but the name is hardly justifiable, since the corals make but a small contribution to this sand; still the corals add considerably to the bulk of the accumulations on the sea bottom and are well worth attention. Small corals are found in many places, but the larger ones belong mostly to the reefs. These reefs are submarine ridges or narrow banks built up of coral and sand. A glance at the map will show that most of our reefs are not situated along the edge of the great bank of sand, but at some little distance within it. The Long Reef at Christiansted, however, and the reef at Buck Island are both not very far from the bank's edge As already said, the reefs are mainly built up of coral. What is coral?

In a tropical island like ours many forms of it are familiar to a visitor to the beaches; but a cursory examination of the dead specimens will not enable us to understand their nature. In school books we sometimes find the praises of the "coral insect" sung as the industrious builder of islands; but, as a matter of fact, there is no coral insect, neither does the living coral "build" in any proper sense of the word. To understand what a coral is we must first study the "animal flowers" that we find along our shores. It is true that some of the most beautiful of these, namely—those which spread out their "petals" from the tops of tubes and are quick in withdrawing them, are worms,* and have no family connection with the corals; but the fleshy ones with sticky arms around their outer edge (sea-anemones) are first-cousins to the corals. Most of these animal-flowers live separately; but on the reefs, and occasionally along the shores, too, a form of these curious creatures may be found which live in extensive colonies, the bodies all joined together by a sheet of flesh below, the upper parts showing as pretty stars with green centres, closely packed together, forming a beautiful piece of natural carpeting. This form carries us very near to the corals; for if we now think of the stars as still further reduced in size, and think of them and the fleshy sheet which unites them as depositing a limestone foundation, we come very near to a clear conception of what a coral is. When we see the stars on the stony coral we now know that they were deposited below the stars on the living animal.

A live coral, then, is a compound animal, feeding its hundreds, or may be thousands, of little stomachs on whatever suitable food the waves may bring to them, and feeding them with the help of the star-like sets of tiny arms that wave over the gelatinous surface, while, as the whole grows, carbonate of lime is deposited below and in the partitions which go from the outer wall of each cell towards its centre. Thus, the living coral does not *build* the stony base, or the stars, any more than a child builds the bones in its body. In both cases, that of the child and the coral alike, the stony material is extracted from the food and lodged in its proper place by the vital processes.

The creatures mentioned above constitute the family of the true corals. There are, however, closely allied kinds which form *horny* skeletons, such as the well known yellow sea-fans and purple sea-fans, and the branching sea-rods,

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* Some of the sea-worms of the West Indian shores are among the most beautiful objects in creation. The large *Sabella*, for example, that inhabits the Lagoon at Christiansted and may occasionally be seen along the shores of the harbour, suggests, with its corolla-like fringe of breathing organs coloured in con centric bands of brown and white, a large and beautiful chrysanthemum. There are other beautiful but smaller kinds, for instance, a bright yellow one always in motion, swinging its arms to right and left in regular time; another, a brown one, that peeps through the sand in groups, and is so sensitive to light and shade that merely passing the hand over the water above it causes the instantaneous withdrawal of the "flower" into the tube. None of these, however, contributes anything to the materials accumulating at the sea bottom, their tubes being simply leathery. On the other hand, there are some kinds which have hard, shelly tubes, and fragments of these may often be found in the sea-sand. There is, for instance, the curious brown *Serpula*, which coils itself in masses over the rocks, and sometimes becomes an actual protection for them. There are others again which form very small shells, flat white coils that may be frequently found adhering to stones and other objects in the shallow water. Both of these kinds occasionally contribute fragments to the sea-sand.

all of which are covered with a fleshy coat in which the small stars are embedded, a coat which contains some lime, and this frequently in definite forms that may be often seen as grains forming part of the sand of the seashore.

Another stony form that exists on the reefs, and on some of them in great abundance, is the *millepore* coral, of which the naturalists tell us that the living creature that covers it and occupies the thousands of tiny holes which give it its name, does not belong to any of the great groups above mentioned, but forms a class by itself. Like the true corals and their allies, it contributes, however, to the material forming the sea bottom around our shores.

The corals of all kinds contribute, however, only a comparatively small portion of the materials accumulating on the surface of the submarine Santa Cruz. An examination of the bottom with the aid of a sea-glass will help us to understand how the sand which covers that great area has been formed, and how it is continually increasing. The glass in question is simply a watertight box open at one end and covered with a sheet of glass at the other; the glass being pressed down on the surface of the water gets rid of all the small ripples which ordinarily prevent our seeing what is at the bottom, and then everything, corals, seaweeds, sea-eggs, starfish, or whatever it may be, becomes quite distinct. We may also learn much by taking up samples of the sand from the bottom and from the seashore, and examining them with the help of our lens.

We shall find that the sand is supplied by many living agencies, which in turn obtain the material from the clear sea-water. Among many other substances dissolved in it, the sea-water contains carbonate of lime. Many seaweeds have the power of extracting this carbonate of lime, and some of them in such a remarkable degree that they come at last to be almost entirely composed of it. When they die and break up they form a large proportion of the sand in some places, for instance at the Round Reef in Christiansted harbour, where one well-known seaweed is very conspicuous as a component of the sand. Other lime-loving weeds have some general resemblance to corals and are known as "corallines"; others again, which mostly encrust rocks, resemble encrusting corals, but from possessing no openings have been called "nullipores."

Sea animals, feeding on the weeds, find the lime for various parts of their bodies, as the shells of molluscs, from the gigantic conch down to the tiny limpet clinging to the rock on the shore, or the shells and spines of sea-eggs, or sea-stars, foraminiferous shells, the shells of crustaceans, and so on. All these creatures, at their death, whether violent or natural, leave the solid parts of their bodies as a legacy to the sheet of material forming on the sea bottom.* When such remains are near the shore they are driven upon it and are broken by the action of the waves into coarse or fine fragments, or are even ground

* The following notes of the contents of a sample of sand taken by the writer from the beach at Cane Bay on the north shore of the island will serve to show how varied are the sources of our sea-sand. The sample was gathered at the wave-margin, and is not so worn as the ordinary beach-sand at the same spot.

The following was the composition of three small portions examined, the grains being separated partly with and partly without the aid of a lens. (See next page).

into powder,† some of the fragments or the powder again drifting out into deep water. In such ways as these the sand at the sea bottom is continually being increased. Some part, it is true, is again dissolved, as we shall presently see, and part of this may be lost, so far as the material at the sea bottom is concerned, but the bulk of it remains, and so year by year the surface of the great bank is being slowly but certainly raised, and the thickness of the bed of material accumulating at the bottom is being slowly but certainly increased.

Contributors to the Limestone Formation.

We may now turn to our marl and limestone rocks to look for further evidence than that of the foraminiferous shells as to whether their origin has been similar to that of the sand of our present seas. Without leaving the Anna's Hope rocks we may already go a little farther than the evidence of the foraminiferous shells will carry us, for we will find here an occasional coral, and at least one bed containing the spines of sea-eggs. Here also, in a cutting, on the southeast side of the road and looking southeast, there is found a layer which to some extent departs from that mode of origin, for it contains a number of pebbles and some sand derived from the older formation. It is worth while to pause and study this fact a little more fully, for the same thing may be observed in many other places, and it has an important bearing on the question of the origin of the soils covering the marl formation. The pebbles are nearly all rounded, as on a beach, an indication that they have been brought down from the ancient land into the sea where the shell-sand was being accumulated and have been rolled about on its shore before being finally buried.

	ORIGIN.	NUMBER OF GRAINS.			TOTAL.	
		No. 1	No. 2	No. 3		
VEGETABLE	Fragments of Nullipore (mostly red)	14	34	27	75	155
	" " Calc. Weed (Halimeda)	7	24	13	44	
	" " Corallines	3	23	10	36	
ANIMAL . . .	Foraminiferous Shells (whole and fragments)	19	47	34	100	158
	Shells, molluscous (mostly fragmentary)	6	21	15	42	
	Fragments of Echinus Spines	3	2	4	9	
	" " small crustaceous Shells	1	0	1	2	
	Minute Serpula Tubes	0	3	1	4	
	Fragments of Echinus Shell	0	1	0	1	
	Agglutinated Grains (same substances)	1	6	9	16	
	Not determined .	8	14	11	33	
	TOTALS	62	175	125	362	

† If we examine with a lens the ordinary sea-sand on an open coast we shall find that most of the sand grains, though obviously fragments of molluscous shells, sea-egg spines, nullipores, or the like, have a rounded form and are beautifully polished, and we can easily see that these peculiarities result form their being ceaselessly rubbed against each other as the waves come and go on the shore.

We can further see that a fine powder must in this way be continually rubbed from off these grains, and if we do not find this powder among them, it is because the sorting power of the water carries it away and lodges it farther from the shore.

After having observed these facts and drawn the plain inferences from them, we need hardly ask for any further explanation of how it is that we find so much finely divided material among the rocks of our limestone and marl formation. Even without allowing for the effects of subsequent changes in the deposited materials, the beach history of a part of them would give a sufficient answer.

We may find a present-day illustration of this ancient process by noting what takes place in Christiansted and the neighbourhood on the occurrence of heavy rains: the streams from the hills bring down large quantities of fine mud, sand, and even pebbles, and lodge them in the harbour. Even in the beds of stone formed on our Long Reef, in a way to be noted later, we may find a few minute pebbles, which perhaps have been carried there attached to debris, such as dried seaweed on the beach or uprooted weeds and bushes which have drifted out from the land. Returning now to our search for evidence as to the regular contributions to the Marl Formation, we find that somewhat similar sections to that at Anna's Hope may be seen, on a smaller or larger scale, at several other points, without even leaving the eastern edge of the Central Slope, and in some of them we shall find abundant evidence of the kind we are looking for.

The most important of these sections is at Cane Garden, where the rocks are cut into by the sea and form a low cliff for a considerable distance along the shore. The layers here are for the most part alternately soft and hard, the soft layers often sandy and containing numerous foraminiferous shells and the spines of sea-eggs, the hard layers generally containing the moulds of finger-shaped corals, that is to say, the corals themselves have disappeared, have, in fact, been dissolved out, while the sand or mud which surrounded them has kept the impression of their forms. This is a remarkable change, but it is one which is very common in limestone rocks. Occasionally, where a shell has been dissolved out, a cast of the interior remains; thus we may sometimes meet with casts of volutes, and several kinds of bivalve shells. It seems also that this dissolving out of parts of the limestone and its later solidification in other spots has had a large share in the process of hardening, which has taken place in the beds after their deposition as loose sand and mud; it has also been the cause of the *concretions* which will be noticed later. That the large beds are sometimes broken through by a number of cross cracks, so as to resemble a building up of separate blocks, is perhaps caused by contraction after the hardening has taken place. This peculiarity is known by geologists as "jointing," and is by no means uncommon in the marl formation, though, as we shall see later, it is much more marked in the blue-beach formation. Thus the section of rocks at Cane Garden is a very instructive one, for not only have we a great number of beds piled one over the other to a thickness, as measured by the present writer, of over 200 feet, but we learn that great changes have occurred since the deposition of the material which forms these beds, changes which have been carried very far in the upper part of the cliff, where the weather has acted on the beds to an extraordinary degree, so that all traces of the original lines of stratification disappear, and the whole of the part affected is converted into a rather soft white marl; not only so, but this surface marl, owing, no doubt, to expansion and contraction, as it becomes wet or dry, according to the seasons, splits into irregular sheets roughly parallel to the surface of the soil. In this way a false stratification arises, which may often be seen in road-cuttings

Casts of Volutes from Montpellier East, Others from Quarry South of Frederiksted.

and like places, and might easily mislead an inexperienced observer to record it as true stratification. After, however, he had seen the lines follow the surface, even on the slopes of a hill on both sides, he would suspect it, and the examination of a section like that at Cane Garden would make the whole matter clear. It has already been noted that the Cane Garden cliffs present alternations in the beds; in some of the layers we have the sea-sand with its minute shells and spines of sea-eggs nearly as the whole was deposited; in others, alternating with these, we see that the rocks have been hardened, while the corals which they had contained are indicated by hollows only, the substance of them having been dissolved away. If we ask why there should be these alternations in the strata, it is only possible to reply in a general way that the conditions must have been continually changing, a general statement which admits of clear illustration, however, by taking a case from our harbour. Just inside the reef itself several shoals have been formed, and some of these consist, on the top at least, of finger-shaped corals, some alive but most of them dead. It is plain that this layer of corals must rest on something else (sand, for example), and if the surface conditions should later be changed the coral layer would in turn be covered by a different accumulation. Now in the limestone rocks at Evening Hill, west of Christiansted, a similar accumulation of finger-shaped corals in beds may be found, so that we have the ancient accumulation and the modern accumulation not far from each other, the latter enlightening us as to the origin of the former.* We may say then, that the lower part of the Cane Garden section, read in the light of an illustration from elsewhere, gives us a good deal of the history of our limestone formation, while the upper part, as shown above, throws light on recent changes which to a large extent obliterate the earlier record.

THINNING OUT.

In connection with the above a condition which may sometimes be seen in a layer in a quarry or roadside cutting should be mentioned. It is sometimes noticeable that a layer does not continue through the whole length of the cutting, but becomes gradually thinner and finally disappears, leaving the layers below and above it to touch each other. An example may be seen at the cutting to the south of the road at Anna's Hope, where a bed of fine gravel *thins out* in this way towards the southwest. If we could see the whole of our limestone beds it is likely indeed that most of them would be found to thin out before they had extended over any large area; that we do not more often see it arises from the beds being generally exposed for rather short lengths.

* It may be noted in passing that these Evening Hill rocks are of special interest, on account of their containing the largest species of foraminiferous shell found on the island, and found, as far as the present writer is aware, at this spot only. The shell commonly measures about a quarter of an inch across, is round and flat, with a bulge in the middle. It contains a great number of very small oblong chambers or rather chamberlets, which make it an interesting shell to examine, and it has a special scientific interest in connection with the determination of the age of our limestone rocks in the world's geological history.

Conclusions from the Foregoing Observations.

Pausing now to sum up the results of our observations thus far, we see that in the quarries and road-cuttings on the hillsides, as well as in the cliffs of the seashore, the peeps which we get at what is beneath our feet in the district studied, show that the whole great mass of the land has been built up, layer after layer, in the sea-bottom by the gradual additions, we might almost say grain by grain, which countless living creatures, both animal and vegetable, have made to it through long ages. If we could remove the verdure and the soil from the landscape, we should see all the hills and the valleys, showing the creamy white colour and the arrangement in layers, of which we have only been able to get glimpses here and there, and we should see plainly that the whole had one common origin. This building up of our limestone formation beneath the sea and from materials extracted from the sea-water is, then, the first great fact that we have learned.

Another great fact presents itself, and it is an obvious one; either the level of the sea has been lowered or the whole mass of this accumulated material has been *lifted* considerably since it was deposited in the ocean. As we shall see later, there is good evidence for the lifting, and it has been so considerable that some parts of the formation are now 400 to 500 feet above the sea level, and at one point, near Bulow's Minde, the height is over 600 feet. Such elevations must have been reached by a great movement, or series of movements, implying the action of great forces; and we must also remember that the base of older rocks, on which all these limestones and marls rest, must have likewise been pushed up. This base we have so far scarcely thought of, but we have regarded it as if it were merely a solid block on which the younger formation rests, and at present it will suit us to continue to think of it in this way, so as to confine our attention to the younger rocks. Still we must not forget that any great movement, of which we find evidence in the upper rocks, must have been shared by the lower rocks; if we see that the limestone formation has been upheaved, then the blue-beach formation, on which it rests, must have been upheaved along with it.

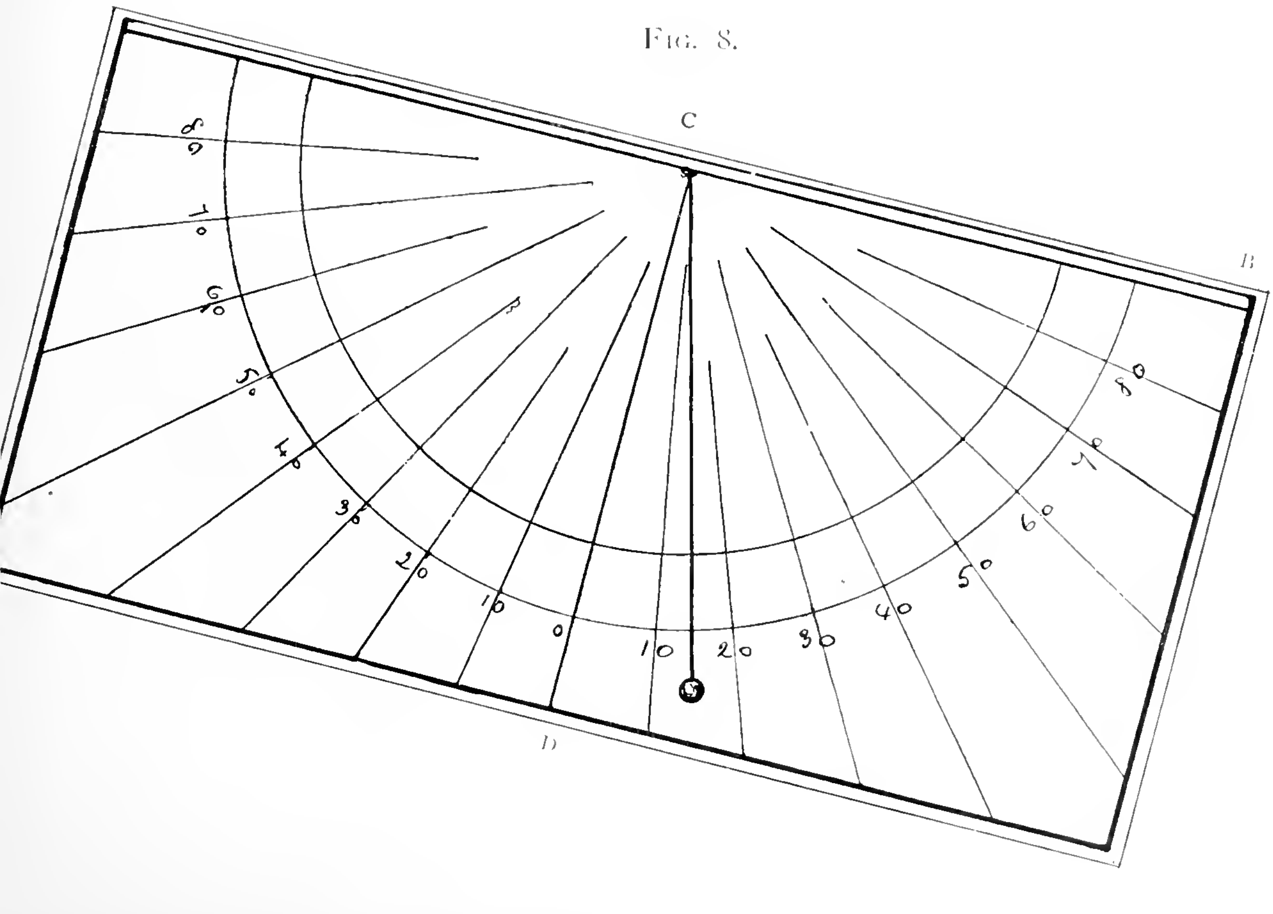
Slope of the Beds.

Studying the great upheaval of which we have seen such plain evidence, we perceive at once that the strata, although laid down, no doubt, horizontally in the sea, or nearly so, have not kept that position during the upward movement, for we have noticed at the places on the eastern edge of the Central Slope, where we have examined the rocks, that the layers slope away, or *dip* as the geologists say, to the southwest, and this will be found to be the case along the entire eastern edge of the Slope; at Bulow's Minde, Constitution Hill, Anna's Hope, Work and Rest, Granard and Cane Garden the slope is to the southwest or thereabouts. The amount of the slope is not insignificant either, but varies from 5 or 6 up to about 15 degrees.

As we shall find later, this question of dip takes a very important place in the study of the history of the rock formations, and is, therefore, worth special attention. Occasionally the layers are horizontal and then there can be no question of dip; but commonly this is not the case, the rocks generally slope in some definite direction, that is to say, towards some definite point of the compass, and this is noted down as the dip; the layers mentioned above, for example, have a *southwest dip*. The amount of the dip is measured in angular degrees from the horizontal, and after a little practice we can generally tell by the eye alone the approximate amount of the dip; but if we wish to measure it more accurately, we must use a simple instrument called a clinometer (slope-measurer). Such an instrument can be bought from an instrument maker; but may also be constructed at home on a card with sufficient accuracy for amateur purposes. The figure below shows such a home-made clinometer.

The Card A B has a semicircle drawn on it, on the edge of which the degrees from one to ninety are marked off on both sides in an upward direction, starting at D. From the centre C a small shot is suspended by a thread, and the lower edge of the card is applied to the layer of rock. The shot, of course, hangs perpendicularly and shows the angle at which the layer under examination slopes from the horizontal. As the beds of rock often present a rather rough surface, it will be found convenient first to rest a straight stick along the rock in the direction of the dip and then to apply the clinometer to the stick, instead of to the rock itself.

FIG. 8.



The line which runs at right angles to the direction of the dip, or, in other words, the line which lies horizontally on the sloping rock-surface, is called the *line of strike*, or simply the *strike*. At *outcrops*—that is to say, at places where the rocky layer crops out, or appears naturally at the surface of the ground, it is sometimes easier to take the strike than the dip. When the strike has been found a very small exposure will give us the *direction* of the dip, which is at right angles to it; but the *amount* of the dip remains to be observed.

Use of the Compass.*

To find the direction of the dip we must use a pocket compass, an indispensable companion in our exploring expeditions, and since the cutting we examine may cross the rocks in any direction, some caution is necessary in noting the direction of the dip. It is seldom that a cutting or quarry will present a face of rock which at once shows us the dip, and we have to observe it on projecting corners, where such can be found, or estimate it from what we see on rock faces having different directions. After a little practice the amateur will find it fairly easy to get the strike and dip of the rocks in any section exposed.

In recording the strike and dip on a map a short straight line is used to show the strike, and another springing from its middle point at right angles shows the *direction* of the dip; the *amount* of the dip may be recorded by the length of the line, which should be long for a low dip and short for a high dip, or both direction and amount may be entered in letters and figures close to the line.

But to return to the southwest dip, which we found to be prevalent all along the eastern edge of the Central Slope, we naturally ask whether the same dip is to be found over the whole of this slope? If not, to what extent does it prevail, and what regulates it? We have noticed that the tilt is from the *east* side, where the hills of the *Eastern Triangle* commence, and it perhaps occurs to us that on the western side of the Central Slope, where the rocks rest against the hills of the *Western Oblong*, it would not be surprising to find a corresponding tilt from that direction—that is to say, from the *west*, and on examining these rocks this is just what we actually do find. For if we study the layers exposed at different points along the *western* edge of the

* A pocket compass can be purchased for about half a crown or 3 francs, and will be found useful for other purposes besides finding the directions of the dips.

There is a very remarkable fact in connection with the compass which ought here to be noted, notwithstanding that it has scarcely any practical bearing on observations taken in St. Croix, and that is *its variation*. It happens that in our island the magnetic needle points very nearly to the true north, but in many other places it departs considerably from that rule. In northwestern Europe, for example, it points to west of north, the variation being in Denmark about 12 degrees and in England 16 to 18 degrees. Here in Santa Cruz the variation at present does not amount to two degrees, say the forty-fifth part of a right angle. It is necessary to say "*at present*," because it is slowly increasing year by year, the annual addition being at Santa Cruz about 3 minutes, or say, the twentieth part of a degree. In the distant future, therefore, it will be necessary, even for an amateur, to make allowance for variation, though at present it is too small to be, in ordinary observations, of any practical consequence.

Central Slope, at Montpellier, Morning Star, Bonne Esperance, La Reine and Barren Spot, we find all these layers sloping, not to the *southwest*, as we found those of the opposite side, but to the *southeast*. We find this same dip also in the piece of the marl formation across the valley and resting directly against the Salt River Hills—namely, at the estates Windsor and Concordia. It is also interesting to notice that the amounts of the dips of this new set are about the same as those of the set previously examined. It appears, then, that if we could cut the beds of the Central Slope through from east to west we should see them sloping inwards from the east and the west towards some central line where they would meet, a line which geologists call a *synclinal axis*, the whole arrangement of the rocks thus sloping together being called *a synclinal*. The case may be easily represented by partially opening a book, when the leaves to right and left will represent the sloping layers of rock, forming the synclinal, and their junction down the middle will represent the synclinal axis. If we further give the book a tilt from one end, calling it the northern end, we shall get a still closer representation of the case before us, for we have found that the rock layers do not dip in from due east and west, but on both sides have an inclination also to the south. The diagram shows how the limestone layers of the Central Slope rest on the older formation. It will, of course, be understood that the black and white bands in no sense *represent* the layers. They merely indicate the slopes of the system.

How to Find the Synclinal Axis.

To find where this synclinal axis runs is a task of no great difficulty, and is of very great interest. The obvious plan to pursue is to cross the slope along several lines going east and west, and to note on a map* the dip of the rocks at every place where we can see it till we get, at all events, the *approximate* position of the line we are looking for. If we commence with the road along the Princess plain, we find, at Belle Vue and the hills around, several quarries and small road-cuttings, all of which show dips to southwest. At Big Princess we find the same, then a southerly dip, and, at a cutting in a range due south of St. John's residence, we find a dip to south-southwest; but at Montpellier and Morning Star, as well as on a road ascending the hills east of the former place, we find that the dip is southeast. Hence we see that the synclinal line passes somewhere near the Estate St. John's. If we take the road along the top of the hills ascending from Belle Vue we find a similar condition; the road-cuttings shew dips to the southwest until we approach the turning where the road goes south to Rattan, and here the dip is southeast. Along the roads which cross the Central Slope more to the south we find southwest dips till we reach the neighbourhood of Diamond and Ruby; but a short distance farther on we find at Barren Spot southeastern dips on the west side of the village, and it is plain that we have crossed the synclinal axis.

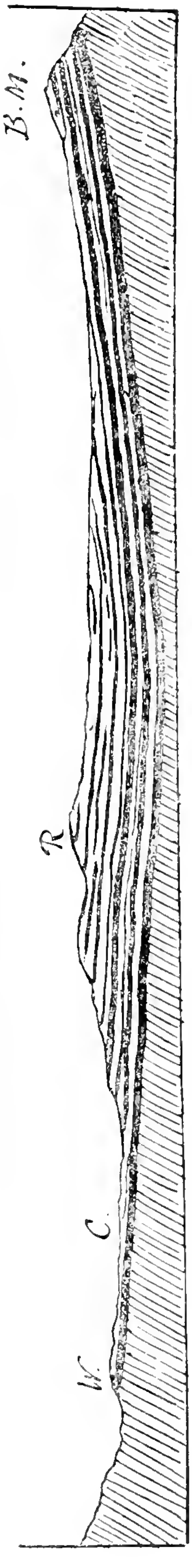


Fig. 9. Section from Windsor to Bulow's Minde Showing the Arrangement of the Rocks of the Central Slope.

* The reader who may wish to follow up this investigation for himself should procure one of Captain Parsons' charts, or the chart of Santa Cruz, published by the Hydrographic Office, Washington, on which to note his observations.

SYNCLINAL OF THE CENTRAL SLOPE

When we look for it on the east side of Barren Spot Village we find a southerly dip, and as such southerly dips prevail on the line north from this position it would seem that the axis must be regarded as lying along a narrow band, across which the dip probably changes in a gradual, but somewhat irregular manner from southeast to southwest.

It is very noticeable that the synclinal axis now traced does not pass down the middle of the Central Slope, as we may have expected after finding the dips similar in amount on both slopes of the synclinal, but that it passes nearer to one side than to the other, namely, nearer to the western than to the eastern side; but this apparent anomaly disappears when we notice that on the west side of the Slope the limestone formation extends right across the valley that bounds the Slope and even rests in a considerable mass (at Windsor and Concordia) against the Salt River Hills; whereas on the eastern side of the Slope the formation ends abruptly on the tops of the hills belonging to the Slope itself. In other words, the boundary valley on the east side has been cut out of the rocks of the older formation, while on the west side the boundary valley has been cut out of the limestone formation itself. This is what gives the apparent one-sidedness to the structure, and it explains some other peculiar features of the district.

It should be noted, however, at the same time that synclinals are by no means always equally balanced; but that it frequently happens that the two sides differ considerably in their relative proportions, a fact which is indeed exemplified, as we shall shortly see, in one part of this very synclinal which we have been studying.

CHAPTER III.

The Limestone and Marl Formation outside of the Central Slope.

Having now taken a survey of the Central Slope and mastered the main features of its structure, we may pass on to study the remaining portion of the Limestone and Marl Formation, namely, that which extends itself along the southwestern coast district and around to the western shore. The beds at Windsor and Upper Concordia must be excluded from this new study, since we have found that though apparently isolated, they not only dip in the same direction as the rocks of the western edge of the Slope, but extend under the valley so as to be continuous with those rocks; hence they must be regarded as belonging structurally to the Central Slope. At first sight it would seem that we might suppose the same to be the case with the limestone beds of the Kingshill Range. The rocks there, as at Windsor, are continued under the separating valley, and when they appear at Kingshill we might expect them, as at Windsor, to dip also to the southeast; but they do not; instead of that, they dip at a low angle (say five to ten degrees) towards the south, and in some places even to the west of south.

This change in the dip of the rocks from southeast to south across the narrow valley will be found to be worth a closer examination In our study of the Central slope we saw that the synclinal axis passes east of the Barren Spot Village, while just to the west of the village the rock layers show the southeastern dip which belongs to the western slope of the synclinal. Yet only a few hundred yards farther to the west (at the old mill on the rising ground across the valley) we find the strata dipping to about southwest, and this rising ground, where such is found to be the case, is a part of the Kingshill Range. Hence the west slope of the synclinal is at this point reduced to a very narrow strip and in this respect presents a great contrast with its width in the north, where it stretches across from St. John's to Windsor and is a fair balance for the wide eastern slope of the synclinal.

How is that? Why is the western slope of the synclinal, which is so broad in the north, narrowed down to next to nothing in the south? The answer appears to be, that a line of elevation passes down the Barren Spot valley throwing the strata on the east side to the southeast and the strata on the west side to the south, and just here to southwest; it also appears that this line of elevation has not affected in the same way the northern strata at Windsor, but must lie outside of them towards the west. Searching for this line of elevation, called by geologists an *anticlinal axis*, our thoughts go back to the Mt. Eagle Ridge. We remember how this ridge divides the waters coming from the northern hills, sending off those on its east side to the *north* coast and those on its west side to the *south* coast. We also remember that the ridge lies northwest and southeast, and if we prolong the line of its axis to the southeast we shall find that this line will pass along the Barren Spot valley; from this valley, in fact, the Mt. Eagle Ridge is seen "end on."

It appears, then, reasonable to suppose that along this conspicuous ridge there lies an *axis of elevation* and that the later lifting movements have thrown off the waters on either hand and have likewise tilted the beds of limestone rock, so that on its northeastern side they dip to the southeast and on its southwestern side to the south, or in some places to west of south.

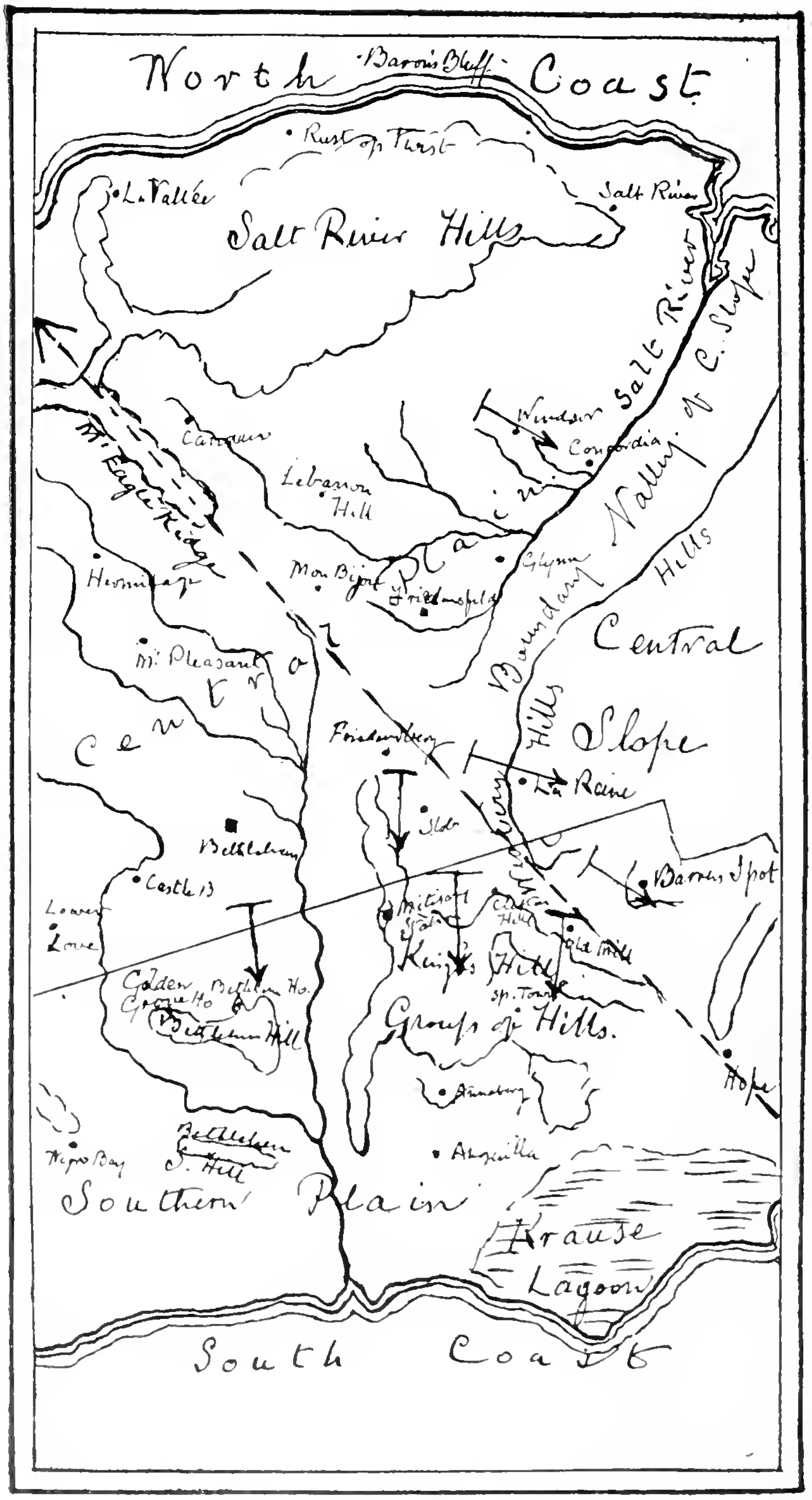
To readers accustomed to studies of this sort the case will have been obvious from the first, and it may seem that too many words have already been given to it; but for the sake of others to whom such studies are quite new it is hoped that some further illustrations of the facts may be permitted. We may again use the open book, with which *the synclinal* and *the synclinal axis* were illustrated, only in this case the open book must be turned with its face to the table instead of upwards, as usual; the leaves on each side will then represent the strata of the *anticlinal* and the back of the book will represent the *anticlinal axis.* As in the former case we may give the book a tilt from one end, calling it the northern end, and if we further suppose a part of the back to be cut away, we shall get a very fair illustration of the facts under review.

The sketch map here given will further help to elucidate the case; it shows the position of the axis and the dips of the strata of the anticlinal (to southeast on the one side, to south by west on the other). In the accompanying section across the Barren Spot Valley from one old mill tower to the other, the dotted arched lines show the positions once occupied by the upheaved limestone strata, the higher parts of which must have been cut away to form the valley and to leave the strata showing on either hand the edges which we now see. The question how they have been cut away, how the arch has been so broken down as to be converted into a hollow, is one of exceeding interest and will become more and more plain as we proceed with our enquiries. Already we have seen hints elsewhere that there have been such removals of the rocks on a large scale, but it is best, so far at least as these pages are concerned, to leave this question for further consideration later.

If we now proceed to examine the west side of the anticlinal just considered, we find the whole block of low limestone hills, to which we have given the name of the Kingshill Range, and which spreads south from Fredensborg, to be made up of limestone strata having similar characteristics to the strata of the Central Slope and all marked by dips to the south, as illustrated by the open and turned down book.

On its western side this hill block is abruptly terminated by the watercourse passing the estate Bethlehem, and we might suppose that on the farther side of the watercourse we should meet with a change of dip, but instead of such a change we find the southerly dip continued through the low hill running westward, on which are situated the residences of the estates Bethlehem and Golden Grove. At both these places the dip is only a trifle east of south. In other words, the influence of the Mt. Eagle anticlinal extends to some distance to the west of the Bethlehem watercourse.

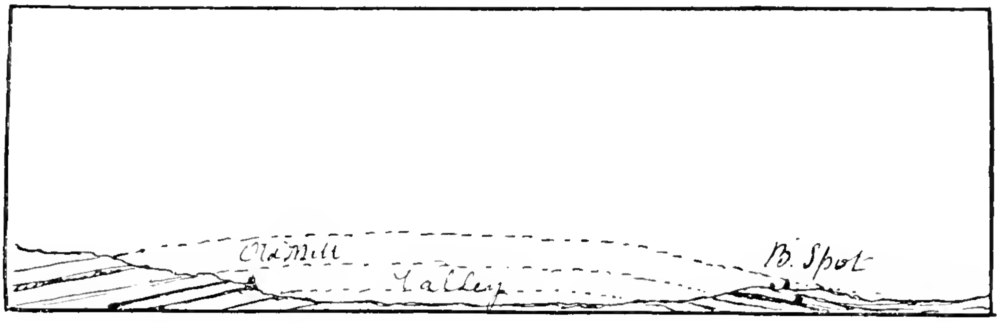
Proceeding a little farther west we find three other small and low limestone hills to be examined. They are all separated from the small Bethlehem ridge



Anticlinal Axis of Mount Eagle Ridge.

by the valley of the watercourse crossing the Central plain from the northwest and joining the Bethlehem watercourse to the south of the residence. Into these three hills the dip of the strata making up the hill last described does *not* extend.

FIG. 12.



SECTION ACROSS BARREN SPOT VALLEY.
The dotted lines indicate position of strata presumed to have been removed.

Starting from the east we find in the first of the three hills (a long low hill on Bethlehem estate, south of the hill above mentioned), and in the second, (the hill at Adventure) that the rocks dip to the southeast, while in the third (the hill at Mt. Pleasant) the rocks dip to the south, not, however, as a continuation of the southerly dip already mentioned, from which it is clearly isolated. The probable explanation of these facts is, that an axis of elevation passes through the northwestern block of hills from northwest to southeast, and is continued towards the southeast between the hill at Mt. Pleasant and that at Adventure, throwing the rocks off on either hand. Thus the rocks on the northeast side of the axis form a slope towards the rocks of the Mt. Eagle anticlinal, which they meet apparently in a synclinal axis that pretty nearly follows the line of the Golden Grove watercourse. It is noteworthy that while the hill at Adventure shews dips to the southeast, its southern end (at Negro Bay mill-tower) shews a southern dip as in the strata at Mt. Pleasant. It is this interesting fact which suggests the direction of the supposed anticlinal axis as being from northwest to southeast, the suggestion being strengthened by the way in which the water is thrown off by the northwestern block of hills, namely, to the southeast on the eastern side of the block, and to the south on its southern side.

THE LIMESTONE FORMATION IN THE PLAINS.

With this survey of the four small hills in the south-central part of the island our study of the hilly portion of the limestone and marl formation closes. The surface of the rest consists of valleys and plains, namely, first the valleys between the hills, then a part of the Central Plain, and lastly, the whole coast plain stretching westwards along the southern shore and along the western shore to a little north of Frederiksted.

In the Central Plain the formation is covered by debris from the older rocks, forming gravelly and clay soils, and masses of debris below these soils,

often of considerable thickness. The presence of this covering makes it impossible to mark the boundary of the limestone formation across the plain with any approach to accuracy, so that the line laid down in the map has in that part very little practical value. If it were required, for instance, to know how far the marl extends under the debris northwards, so as to get at it for agricultural purposes, it would be necessary to decide the point by borings. Some years ago a boring for a well was made near the Bethlehem Works, to the north of the Centre-line Road, and after a few feet of debris, a thickness of 150 feet of marl was passed through; hence we are safe in carrying the line north of the Bethlehem Works. A few hints further west enable us to carry it along the north side of the Centre-line Road past Lower Concordia, and then northwards back of Frederiksted to the coast. In contrast with the uncertainty as to the boundary over this plain, we find that the boundary around the Central Slope is not difficult to fix and will be found to be very nearly as laid down in the map.

The plain country of the southwest affords only a few exhibitions of the marl rocks in low cliffs (or vertical banks) on the seashore, and in shallow road-cuttings here and there. At Betty's Hope and some other places these banks contain a great number of very hard limestone nodules of irregular forms, apparently concretions or, perhaps in some cases, concretions that have been partly rounded by water. The concretions may be seen in the shallow road-cuttings and in the banks along the shore at Betty's Hope. At Long Point the rocks contain a great number of impressions both of shells and corals, and in some places the fossils themselves have been left. Neither in these cliffs, although some parts are over 20 ft. in height, nor in the few shallow road-cuttings in this part of the country do the rocks show any distinct stratification, and it may be that they form a thick mass nearly or quite horizontal.

At Frederiksted we have the remarkable limestone already described. The quarries are to the east of the town; the strata are somewhat irregular and much broken; they dip away at a rather high angle (about 25 degrees) to the west. Considering that the island ends abruptly along its western shore, this steep dip to the west is very suggestive. It would appear that the lifting force which brought up these rocks was greatest somewhere to the east of the town. Where is that line of elevation, that anticlinal axis? It probably stretches from northeast to southwest through the northwest hills, and is continued along the spur that comes down towards Concordia, ending in the long point (Sandy Point) which stretches out at the southwest extremity of the island. This view is strengthened by the geography of the marls in this part of the island, namely, their lying along the south coast on the east side of the supposed anticlinal, and along the west coast on the west side of it, and it is also confirmed by the flow of the surface waters from the northwestern hills, namely, towards the south on their southern side and towards the west on their western side.

At the entrance to the town of Frederiksted there are some beds of lime-

stones and marls cut through for the roadway. These beds dip at a moderate angle to about south-southeast. They, like the beds below them, are full of corals, but they appear to have been put down much later than the rocks in the large quarry. It seems indeed that the two sets are well marked off from each other at West End, that the southerly dipping rocks have been put down over the westerly dipping rocks, and have been tilted at a later time by a movement from the north, the last, perhaps, of the movements that have given the island approximately its present outlines. It is probable, moreover, that the southern dip, mentioned as belonging to the upper rocks at West End, does not extend very far, but soon gives way southwards to a horizontal arrangement, which is what appears to prevail over the whole of the southwest plain.

It must be admitted, however, that the geological evidence for the supposed anticlinal axis through the northwest hills and continued to seawards through Sandy Point is not strong. It has already been mentioned that the stratification in the big quarry on the east boundary of the town is irregular, and when we examine the different small exposures south of the town and the more important one in the large quarry near the north end of the Salt Pond, the quarry at present being used for procuring limestone for the Central Factory, we see no evidences of a westerly dip, or, indeed, of a dip of any kind. The mass of limestone is not stratified, but suggests deposition in the neighbourhood of a reef through a long period of time. Some coral and numerous shell casts are to be seen. The greater part of the rock has been redeposited from solution, is nearly pure calcite and very hard, often with channels and openings in different parts of the quarry, in which there are clear evidences of the action of underground water. The same is to a great extent true of the great West End quarry, but not of the rocks at the entrance to the town, which are very little altered, are clearly stratified, and contain well-preserved corals, small fragments of molluscous shells and sea-egg spines. The limestone rocks of the west end of the island present, indeed, a difficult, and therefore attractive, subject of study.

Irregularities.

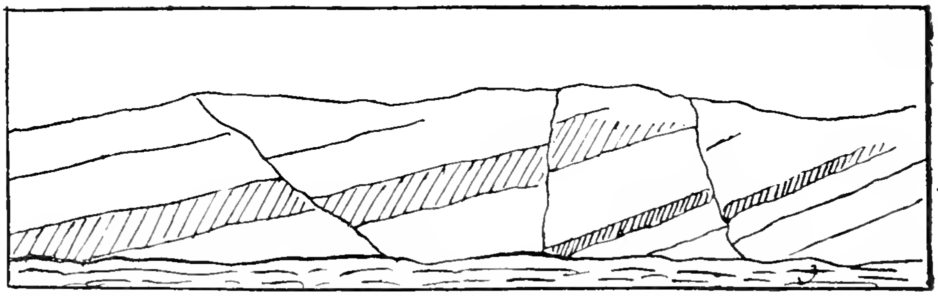
The reader who follows up by actual observations the study of the arrangement of the limestone rocks described in the preceding pages, will find occasional irregularities that have not been hitherto mentioned. The principal of these known to the present writer is in the neighbourhood of Sion Hill and on the road from that estate to Sion Farm. Here in the road-cuttings it is sometimes seen that the marl-beds are about horizontal and occasionally dip slightly to the southeast. This peculiarity appears, however, to be merely local; for it does not seem possible to trace it through the formation either towards the north or towards the south, all the dips observed in those parts being to southwest or thereabouts.

Another irregularity, which in this island appears to be of little consequence as affecting the arrangement of the rocks on a large scale, is neverthe-

less very interesting and will not escape an observer's attention. It is the occurrence of breaks across the strata, breaks which the geologists call *faults*. The accompanying sketch, taken from the cliffs at Cane Garden, will show clearly what is meant by a fault. It will be seen that the whole mass of the strata visible in the cliff has been broken across, and that in each of the three faults shewn, the beds have slidden down a little on one side of the break. Here the slide is of very small amount, but faults are known to geologists where the difference of level in the beds on opposite sides is very great, and among mountains sometimes amounts even to several thousand feet. In our marl formation there does not seem to have been much cracking and sliding of the strata in this way; at all events very few faults show themselves.

The name "fault" is perhaps an unfortunate one, but it is easy to see how it has arisen, for when the miners in following up a bed of coal or a mineral vein are suddenly stopped by a wall of other beds, not containing the mineral they are working, they naturally regard the arrangement which gives them trouble as a fault.

Fig. 13.



Faults in Limestone Rocks at "Cane Garden."

It will be noticed in the sketch, that it is the masses on the *upper* sides of the sloping lines of fault which have slidden down. This is the case with the great majority of faults, and arises from the fact that the rocky mass on the upper side of the slope has a smaller base, hence less support, and consequently greater tendency to settle down when disturbances of the earth's crust in their locality take place. It is not difficult, however, to conceive of a fault being produced during a time of great side pressure while the rocks were being lifted, and in that case the lighter mass, the mass with the smaller base, would be pushed upwards, and the common rule would be reversed. Such faults are called "up-thrust" faults. To that class belong many of the great faults of mountain regions, and examples on a small scale may also be found in the older formation in our own island.

Thickness of the Limestone Formation.

An enthusiastic observer will no doubt find many other points of interest in the study of the limestone and marl formation as he proceeds; here we must be content with only one more enquiry, namely, what is the greatest thickness of the formation as it now exists? This question may be answered approxi-

mately when we notice that on the Princess Plain the strata come out in advance of the hills which here border the Central Slope, and dip away under them in a southeasterly or southwesterly direction, while the hills themselves reach heights of 400 to 500 feet (at one point 600 feet). Hence a thickness of at least 600 feet would not be too much to allow for these deposits, an estimate which we shall scarcely consider as too great when we remember that the moderate length of cliff at Cane Garden shows, as ascertained by measurement, a thickness of over 200 feet of strata.

Beach and Reef Limestones.

We have now studied the limestone formation in the hills, valleys and plains that have been carved out of it, but there still remains a class of limestone rocks which, though much younger than those we have been studying, indeed quite recent, are of very great interest, because in them we see, as it were, the sand of the sea being converted into rock before our eyes. In various places along our sandy shores we find hard, solid beds of rock, which on being broken into show themselves to be nothing else than grains of sand firmly bound together. They are, in fact, made from the shore sand. When these beds are out of the water or exposed at low tide we may conceive that the binding material has been dissolved from the sand itself by rain-water containing carbonic acid gas in solution and has been deposited again amongst the sand grains when the rain-water was afterwards evaporated; but we find similar rocks on the reefs, where they are always under water. There is, therefore, some other source of the carbonic acid than the rain-water, and this is probably to be found in the carbonaceous matter of the animals and seaweeds that are buried in the sand. At the reef at Christiansted the rock is sometimes broken off in large pieces with crowbars and brought ashore to be used for building purposes; hence, blocks of this rock may be seen here and there in walls in different parts of the town, and they show particles of shells or seaweeds, according to the character of the sand from which they were formed. For the most part they appear to be quite as durable as the stones from the quarries. Sometimes fragments of such rocks from the reef, on being broken through and examined with a lens, show the sections of the sand-grains surrounded by a white ring of carbonate of lime, and the same enclosing case is seen around the small pebbles from the Blue-beach formation which are occasionally found mixed with the shell sand. At Frederiksted this recent limestone rock is not only found along the shore, but in the flat part of the town, where it extends itself inland eastwards, so that several streets are built upon it. Here the recent date of the rocks may be determined, not only by the fact that some of the shell fragments have retained their original colours, but also by the presence of a particular foraminiferous shell that is abundant in our sea sands at the present time. (See Fig. 11 on Plate B.) Though so recent a rock, it has already been acted upon by the weather so far as to be converted near the surface of the ground into a white mass, in which the sand-grains be-

gin to disappear and which breaks loose in an irregular manner from the remainder of the rock below. In other words, it is converted, just as in the older limestones, into a white marl.

SUMMARY.

With the study of the above described very recent rocks we have completed our general survey of the limestones and marls of the island, and may now pause to summarize the results of our studies before proceeding to give attention to the older or "Blue-beach" formation, on which all the rocks of the later period rest. We have learned, then:

1.—That the limestone formation covers the central, south-central and southwestern parts of our island.

2.—That the rocks are arranged in strata piled over each other to a great thickness.

3.—That the whole mass has been formed in the sea by the gradual accumulation of animal and vegetable remains composed mostly of carbonate of lime which the living creatures have extracted from the sea-water.

4.—That at different times during the deposition of the limestones and marls, considerable quantities of pebbles and finer debris from the older or "Blue-beach" formation have been washed into the sea and mingled with the accumulations which the sea-creatures have furnished; from which it may be inferred that land of the older formation was not far off during the deposition of the younger formation.

5.—That great changes in the condition of the rocks have taken place since they were deposited, the carbonate of lime having in many cases been dissolved and, in part at least, re-deposited in other forms, a change which accounts for the hardness of some of the beds, and for the formation of concretions, and which has extended also to many of the fossils deposited with the rocks. Another important change is shown by the jointing of many of the beds.

6.—That the whole mass has been raised from the sea-bottom to some height above the sea-level (certainly 600 ft., and in the first instance probably much more).

7.—That the slopes or dips of the rocks show that the elevation has been mostly from the north, but that the dips are also affected by lines of elevation and of depression which lie in two directions, namely from about northeast to southwest, and from about northwest to southeast.

8.—That as a leading result of these movements the central part of the island forms a depression or sort of cross valley filled in with the marl formation, the removal of which from it would leave a sea-channel across the island from north to south, making of the Eastern Triangle and the Northwestern Hills two separate islands. We must remember, however, that this depressed portion

was level or nearly level when the deposits were made, so that these may have extended, and probably did extend, far beyond their present boundaries.

9.—That the rocks have in many places been greatly altered near the surface of the ground by the weather, sometimes to such an extent that the original stratification has been effaced and a false stratification, resulting from expansion and contraction in alternating wet and dry times, has taken its place.

10.—Lastly, we have seen in the varied surface of hill and dale a proof that the mass of strata has not remained in the form in which it was lifted from the sea, but has by some means been sculptured into the existing beautiful undulations. The study of this interesting subject is, however, best left over till after we have examined the rocks of the older formation, which, even to a far greater extent than the younger rocks, have been subject to the sculpturing processes.

CHAPTER IV.

The "Blue-beach" or Indurated Clay Formation.

As already mentioned, the "Blue-beach" formation is found throughout the Eastern Triangle and the hills of the Western Oblong; in fact it occupies all parts of the island not occupied by the limestone and marl group. Not only so, but it passes under those rocks, and is the base on which they all rest. It is therefore the principal, as well as the older formation.

In comparing, at the beginning of our studies, the rocks of the two groups, it was pointed out that by the simple experiment of dropping a fragment of each into water containing a little nitric or muriatic acid it can be seen at once that there is some great difference in their composition, for while the fragment from the younger group effervesces and at last almost disappears, the fragment from the older group is scarcely, if at all, affected. For a proper account of their composition, however, we must look to the chemists, and they tell us that these older rocks are mainly composed of alumina and silica, the substances which in combination form clay, silica by itself forming flint, quartz and similar substances.

In 1839 an American geologist, Prof. S. Hovey, published some observations on the geology of St. Croix. He distinguishes the two formations of the island, and calls the older one the *Clay Formation*. He also mentions it as *indurated clay*, a better name, since the rocks, though like clay in their composition, have been made intensely hard by processes to which they have been subjected since they were deposited. He speaks of their composition as various, in some cases silica, in others alumina, predominating. He also states that some of the strata near Mt. Victory resemble slates.

In 1868 a Swedish geologist, Prof. P. T. Cleve, visited the northeastern West Indian Islands and gave an account of their geology. In describing the geology of the Danish Islands he restricts the local name "blue-beach" to a conglomerate which is abundant in St. Thomas, and he speaks of some of our Santa Cruz rocks as resembling the said "blue-beach conglomerate." Locally, however, the term "blue-beach" is applied to all the hard crystalline rocks of a blue or green colour, and the term "rotten-stone" to the same rock when broken up by weathering, as we see it in the so-called gravel-pits. Prof. Cleve also speaks of clay-slate as abundant east of Christiansted and northeast of Frederiksted, and gives many other interesting particulars, to some of which we may refer later.

The amateur study of the older rocks is at first rather discouraging, for they often show no sign of any arrangement, but look like mere masses of rusty material, presenting no hint as to how their study is to be undertaken. We find out, however, as we go on, that they give in many places clear indications of regular stratification. In many of them these indications consist merely of ribbon-like markings on their outer surface, but sometimes the layers are also divided along surfaces corresponding to those markings, so as to leave no possible doubt of their stratified arrangement.

Rocks Showing Stratification Marks, Contentment Road, Near Christiansted.

The materials of which these rocks are composed have not, like those of the limestone rocks, been extracted from the sea-water, but have been washed down from the land into the sea. If we notice what happens in the harbour at Christiansted after heavy rains we shall understand how thin layers of such deposits may be laid down. The streams after such rains come down from the hillslopes laden with mud and sand, which settle along the shore and for some distance out in the harbour, each influx producing a thin addition to the deposits. Further light is thrown on the subject by the experience of Martinique and St. Vincent after the volcanic eruptions of 1902, when vast quantities of the dust and stones thrown out by the volcanoes were washed down into the sea. As we proceed we shall find some reason to suppose it likely that the older rocks of our Danish Islands, and perhaps the whole chain to which they belong, may have originated from volcanic action, but we must not be too sure of that; what is quite certain, however, is that these rocks have been formed by debris brought down from the land and arranged in strata in the sea bottom.

After having found that the rocks we are now studying are, at all events to a great extent, stratified, it strikes us as very strange when we discover that they are at the same time *crystalline*, for the materials of which they are composed are not, like carbonate of lime, easily dissolved in water and redeposited in a crystallized state; but it is known that such materials require also a high degree of heat to change their form. It appears, then, that these rocks have been subjected to high temperatures, since their deposition as mud and sand in the ancient seas, and by such high temperatures and the presence of water at the same time, have been so far altered that their stratification for the most part has disappeared, to make itself evident, however, when the weather acts on the exposed surfaces and reveals the stratification anew. In some cases, however, the changes seem to have gone so far that the mass shows no sign whatever of stratification, but resembles those rocks that are found in many parts of the world with forms so plainly showing the action of heat that they are known as "*igneous* rocks."

We do, indeed, find here and there in the older formation of this island some masses of rock that evidently have been forced up from below and are genuine igneous rocks; but these cases are few. The great mass has undoubtedly been first deposited in sedimentary layers and has afterwards been changed by heat. The name igneo-sedimentary has sometimes been given to such rocks. In a few of the strata the change to the crystalline form has not been carried very far, and these are of great interest, because the records of the past are best preserved in them, as we shall shortly see.

Having convinced ourselves that the rocks of the "Blue-beach" or clay formation, in spite of their crystallization, are in reality stratified rocks, we may next proceed to study the facts connected with the strata, and the first thing that strikes us is the high angle to which they have been forced up; so that, while the limestone rocks of the younger formation dip at low angles of 10 to 15 degrees, the older rocks commonly reach at least 45 degrees. On the

eastern and western borders of the town of Christiansted, at Judith's Fancy and at many other places, such a dip may be observed. High dips are, in fact, general, in whatever direction the rocks may slope. Although occasionally less than 45 degrees, it is in some places much greater; near West End, for example, where the road past "Wheel of Fortune" runs over the upturned edges of these rocks, the dip reaches as high as 70 or 80; at "Waiter's Point," south of Christiansted, on the southern shore, some of the layers are absolutely *upright;* while along the south shore of "Buck Island" the tilting of the strata has been carried further still, so that some of the layers, which at one place are vertical, are, at a short distance farther on along the shore, carried so far over that they actually pass the upright and so come to dip in the opposite direction, showing what the geologists call a "reversed dip."

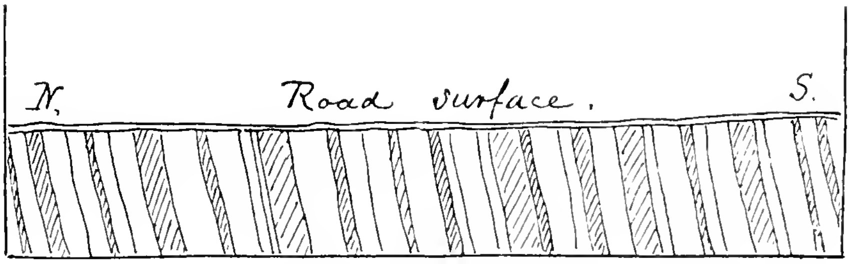
Relative Positions of the Two Formations.

There is no spot known to the present writer where the limestone formation may be seen in actual contact with the rocks of the older formation. While, however, there does not appear to be any exhibition of the actual contact of the two formations, there are many places where the relative positions of the two sets of rocks are plain enough. For example, on the Bulow's Minde hill, where the limestone which caps the hill is succeeded lower down by "blue-beach" rocks, as shown in "gravel pits" and by the gravelly character of the soil. The same is seen at a point further south—namely, on the hill near Granard, where the brow of the hill looking east shows limestone beds, while lower down these are succeeded by gravelly soil derived from the older formation. Again at West End (Frederiksted) the limestone formation extends eastwards to include the small hill back of the town, and then gives way to the gravelly deposits derived from and extending towards the "blue-beach" hills. The neighbourhood of West End presents, indeed, a most interesting exhibition of the relations between the two sets of rocks. It has already been mentioned that the layers of the older rocks have been lifted to very high angles (70 or 80 degrees), and they may be seen in a gravel pit and in the road trenches from near Concordia to near Wheel of Fortune. They dip at the steep angles named towards south by east, and the roadway runs on the upturned edges, as shown in the diagram (Fig. 14). These layers are very distinct as seen in the trenches, and are sometimes shown on the roadway itself in a very interesting manner; the differences in the composition of the various layers have given rise to differences in the rates of their decomposition, so that it has gone deeper into the edges of some of the strata than into the edges of others; hence, some of these edges retain water better than others, and when the road is drying after rain these more absorbent strata are indicated by damp bands across the roadway. For the same reason vegetation is sometimes seen to be more vigorous along some edges than along others, and in this way a field of guinea-grass east of the town of Frederiksted not infrequently shows the direction of the edges of the strata by alternating bands of a darker and a

Stratified Rocks on the Shore West of Fort Augusta, Near Christiansted Harbour.

lighter green. Even the coarser vegetation shows in one place a like result—namely, on the south side of the northwestern block of hills, where on the side of one of the hill-spurs the direction of the stratification may be recognized from a distance of a couple of miles to the eastward by the parallel lines of flourishing bush vegetation passing down the hillside.

FIG. 14.



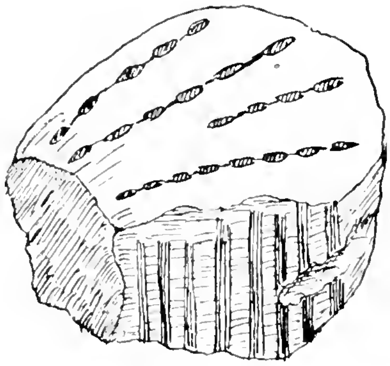
HIGH DIP ALONG WEST END ROAD.

The dip to the south, above considered, extends over an extensive area, as we shall presently see, and it is on the upturned edges of these highly inclined strata that the moderately sloping limestones at West End rest. In geological language the limestone rocks here are said to rest unconformably on the Bluebeach, and the same is undoubtedly the case in all other parts of the island where the limestone formation is found. Let us, however, leave this question for the present and return to the study of the early history of the older rocks—that is to say, the history of their making. While it is certain from the fact of their stratification that these rocks were deposited in water, and almost certain that the water was that of the sea, yet it appears at first sight that we can get no other evidence on this point, the general absence of fossils giving us the idea that the sea surrounding the land of that day was so disturbed by the continual influx of detritus, volcanic ashes and debris perhaps, from the shore, that the sea creatures had no chance to contribute even an occasional bed of limestone to confirm the hint which the mere fact of their stratification affords, that the rocks were built up in the sea. And this idea of the prevailing conditions, with certain limitations, is probably in the main correct; yet as we continue our observation of the rocks, we find, contrary to our first impressions, that there are after all a few remains of limestone beds, and that these present clear evidence of their origin in the sea. One of these beds of limestone is found in a little hill near the shore on the estate St. John's and near to Judith's Fancy. Professor Cleve thus writes of it: "Greyish compact limestone is found, as far as I know, only in one spot, near Judith's Fancy. The rock is hard, dark grey and fine-grained. It contains a great number of badly preserved fossils, so altered that I have not been able to find out of what kind they are." He also mentions a band of greyish limestone in Buck Island; a band which is not known to the present writer. It does not seem, however that the Professor's attention was called to the rocks at Waiter's Point, a headland on the southern shore nearly south of Christiansted, where the strata are particularly interesting.

On the east side of Waiter's Point the rocks are very similar to those common around Christiansted, externally brown and plainly stratified, but without fossils, the strata dipping at about 45 degrees to the southwest; but when we pass to the western side of the point we find a set of strata of varied character and standing at very high angles, some of them absolutely vertical. A fossil sea-egg, for example, has been found here on the surface of a bed of gritty rock now quite upright, which, when the sea-egg lived on its surface and was embedded in the sand, was certainly level or nearly so.

The strata here consist of limestones, indurated clays, etc., and at one place there is a rather extensive intrusion of igneous rock from below. Some of the limestones are compact, but others seem to be made up of broken fragments cemented together, and at least one bed of gritty rock seems to contain waterworn fragments of the same limestone. In the limestone layers, numerous specimens of a very curious fossil are embedded. In outward appearance and in the cross-section these so much resemble plant stems of some kind that the present writer has hitherto regarded them as such, but, on submitting some of them to scientific examination in New York recently, has been informed that the apparent stem fragments are of animal origin, showing "coralline or some similar animal structure." One of the best specimens collected is several inches in length and about seven inches across. It has in one part a black outer covering, suggesting the bark of a stem, while running up through it and parallel to each other there are black columns that look like the bundles of fibres that run through the stems of some plants. The arrangement is shown in the accompanying sketch of a small fragment (Fig. 15). In the above mentioned larger specimen, there are fifty-four of the radiating lines of black spots, such as those shown in the diagram. Presumably the creature, parts of whose form we find preserved in these fossils, was a gigantic animal-flower (sea-anemone), from which the spreading arms of the top have disappeared. Possibly the lower or stem-like portion of the creature was strengthened by a considerable deposit of lime in part of the flesh; for it seems difficult,

FIG. 15.



otherwise, to see how the form could have been so well retained as we actually find it In any case, we have here a fossil of great interest and that may possibly be of some value to geologists in helping to find the relation of our St. Croix strata to those of other parts of the world.

Fossil fragments similar to those described above are to be found in the cliffs near to the ancient limestone rock at the estate St. John's, and also at the estate Salt River, where they may be seen in some thin beds that cross the main road. Besides the fossil remains above mentioned, the limestones at all the places named contain foraminiferous shells, the section showing a coiled shell with numerous chambers.

Conglomerates.

Leaving the subject of the fossils, we may now turn to another interesting question, namely, the occurrence of conglomerates in the blue-beach formation. Prof. Hovey, in his notes already referred to, remarks in reference to these rocks "no conglomerates," and this must certainly have been correct for the rocks he examined. The present writer, indeed, has not noticed any conglomerates among the rocks of the northwest, which appears to have been the part examined by the professor; but has seen them in other parts of the island. At the west end of Buck Island there is a bed of true conglomerate ("pudding-stone"), that is to say, the pebbles are all thoroughly water-worn. In other places may be seen conglomerates in which the embedded fragments retain entirely or in a great degree their angular form, the stone belonging more nearly, therefore, to what the Italian geologists called "breccia." Detached blocks of rock of this sort may be seen at Hermon Hill; while at Salt River Point there is a great mass of rock of similar character. The same is true of the point projecting northward in the middle of the Salt River. At Hermon Hill the blocks have evidently been broken off from a thick layer, which, however, the present writer has not been able to locate; but at the two points mentioned no stratification can be made out, and the appearance of the rock suggests that it has been a mass of debris, such as we now see spread over our Central Plain, and has been subsequently hardened. Professor Cleve, speaking of the St. Thomas rocks, says: "the occurrence of scoriaceous (cindery) pieces in the conglomerate indicates its volcanic origin." Though not seen by the present writer, it is not unlikely that conglomerates of similar character exist also in St. Croix.

Travertine.

Reviewing what we have so far learned in regard to the origin of the older rocks of our island, we may say that we have seen that they were formed from debris of greater or less fineness, and most likely of ultimate volcanic origin, brought down from an adjacent land by streams into the sea, forming there mud deposits and conglomerates arranged in definite layers, subsequently to be altered to the hard rocks,which Professor Hovey describes as indurated clay, and

further that the sea, at one time during the long period of the piling up of the clay rocks, not only received and arranged all this material, but also furnished its own quota in the shape of a few limestone beds, which in some parts, as in the limestones at St. John's estate, are so nearly pure as to contain over 90 per cent. of carbonate of lime; in other parts, as at Waiter's Point, mostly impure, but containing numerous fossils of considerable interest.

The presence here and there of limestone beds in the blue-beach formation, taken together with the power of carbonic acid to dissolve carbonate of lime, suggests to us that after all there may have been other, even though less abundant, deposits of lime elsewhere throughout the formation, deposits which have disappeared under the dissolving process. In that case we should be in error if we inferred from the absence of such beds an absence of sea-life during the period or its powerlessness to leave any record. And this view of the matter is strengthened by the fact that some of the older rocks do contain a fair amount of lime in their composition. In the northwestern hills the presence of lime in the rock is shown in a most interesting way. On the road up the hill from "Little La Grange" to "Punch" an old watercourse is cut through, in which some exceedingly curious deposits of limestone may be seen. The limestone is in masses having rounded tops, and when carefully examined is found to be light and porous, to be made up, in fact, of small cells, somewhat irregularly arranged in thin layers, one over the other. The rock also contains impressions of stems and leaves. The origin of this singular rock, which is called "*Travertine*," may be seen in the neighbouring stream that passes down the beautiful valley known as Crequi's. There some of the larger blue-beach rocks in the bed of this stream may be seen to have acquired a similar rounded form, the covering being a substance composed of like material, and if examined while the water runs over them, they will be found to be covered with a slimy vegetable growth, a growth which doubtlessly absorbs the lime brought out of the rocks by fresh water, and on the subsidence of the water dies, leaving a limestone crust. Such crusts deposited one over the other, through a long period, make the blocks such as we see in the above-mentioned old stream-bed. No similar growth of Travertine has been found by the present writer in the other streams of the island; but in the watercourse which passes out into the plain near Grove Place, he has found among the pebbles a water-worn fragment of this curious rock, proving its existence higher up in the stream s course. While, therefore, the great preponderance of the clay class of rocks in the blue-beach formation is obvious, we have to modify our conclusions so far as to admit that the lime deposits may have been originally more numerous than now appears.

Although we have thus come to a conception of the origin of our older rocks, which is probably near the truth, there remain many interesting points in regard to them yet to be studied.

The crystallization of many of the rocks, which obliterates the stratification, and the weathering which so often reveals it again, have already been men-

tioned. Another curious change in the rock has been the development in it, in some places, of numerous small bodies resembling peas in shape, and generally in size also, though sometimes much smaller. This singular result is shown abundantly in the rocks in Christiansted and the neighbourhood; but may also be seen in many other places. It has arisen from the tendency of some component of the rock to get together into small masses; it is, in fact, a sort of imperfect crystallization and is technically known as concretion. When the rock is acted on by the weather, the little balls stand out on the surface of the stone, in other cases they have been cut through where natural splits in the rock have occurred, and then they are represented on the surface by small round patches, generally of a lighter colour than the rest of the stone.

A quarry near the roadside east of Christiansted presents some evidence as to the way in which the process went on. We see on some of the rock faces there very thin bands of paler colour than the rest of the surface, the edges, in fact, of thin layers. In some cases we see these bands broken into short lengths, as if the material which gave the lighter colour had been drawing together in patches; while in other cases again the process has been completed, the material has been collected in little balls all along the line. In the majority of instances, however, the structure in question has arisen in much thicker beds, and then there is frequently very little regularity in its development.

The structure above described is called by geologists *variolitic*, a word which refers merely to the variation produced in the stone by the concretionary process. Its occurrence in the rocks is often of great assistance in the determination of the dip. In availing ourselves of its aid for this purpose it is necessary, however, to use a little caution; for it sometimes happens that the structure tends to follow the *joints* of the rock, and if we are not aware of this fact we may be misled into taking the direction of the jointing planes for the direction of the stratification. Generally, however, a careful study of the case will save us from this error.

In connection with this variolitic structure, another effect of a somewhat similar nature may be noted. A few layers of the older formation may be found in which the tendency of some constituent of the rock to collect towards definite points is shown in a very curious result, namely, in converting the whole bed of rock into a number of rounded bodies composed of successive layers, which, under the action of the weather, peel off like the coats of an onion. These rounded bodies are all close together, so that the rock is quite solid, but where the weather acts on it they show themselves, and the coats commence to break away. Such a layer of rock with concretionary forms of this sort, most of them three or four inches across, may be seen in the bed of the stream which passes under the new bridge south of Cornhill.

Another interesting fact is the splitting of the indurated rock in various directions, so that the fragments generally present several straight sides, the

faces being flat. The planes of divisions are technically called "joints." The tendency to split in this way is very common, and generally becomes conspicuous when the rock is acted on by the weather; in some cases, however, the rock is solid and very hard, and only comes away in large blocks. Sometimes the jointing is so regular in parallel planes in a given direction that we have to be on our guard not to mistake it for stratification.

Perhaps the most remarkable change of all, a change allied, may be, in its nature to that mentioned above, is that which has taken place in the slate rocks. Essentially these rocks resemble in composition the other rocks of the older formation, but the texture is very fine, and they have undergone a process which has originated a structure called cleavage. Cleavage is a peculiar property that distinguishes slates from all other clay rocks. It is the tendency to split along parallel surfaces into slabs of varying thickness according to the quality of the rock. These cleavage surfaces or planes do not follow the planes of stratification but are often placed at a considerable angle to them. They are, in fact, quite independent of the way in which the material has been put down, and have arisen from the enormous pressure to which that material has been subjected later. In the well-examined slate districts of European countries and North America, it has been shown that the direction of the cleavage depends on the direction of the neighbouring axis of elevation; it follows in a general way the direction of that axis, from which it may be inferred that the pressure which has forced up the wave of the earth's crust, known as an anticlinal, has also pressed on the clay rocks with such intensity that they have rearranged their particles in the form of adjacent plates. The fact that pressure has caused this rearrangement cannot, so far as the present writer knows, be shown in the St. Croix slates, but in other lands, where fossil shells are sometimes found embedded in the slate, it is seen that the shells are lengthened in the direction of the cleavage and shortened in the cross direction; they have, in other words, been squeezed out of shape and always in the way described. What is thus próved for many slate formations may be assumed as true of ours. Professor Cleve, writing of the clay-slate of St. Croix, says that "it is perfectly cleavable," that is to say, he found that he could split it along the cleavage planes in the same way as the European or American slates are split; but this must not be taken to mean that they have any commercial value; the beds are neither thick enough nor fine enough for that. The cleavage is also most generally irregular, as far as the present writer has been able to ascertain, and the slates are frequently in thin beds, and these are often interstratified with other rocks, which show the cleavage in a less distinct way.

It may also be noted that the planes of cleavage in the slates are sometimes shown by fine white lines along the surfaces of splits in the rock; and the edges of the thin slabs occasionally appear as tiny parallel waves. Thus it will be seen that the cleavage is a very interesting feature of the slate rocks, and leaves room for extensive study, equally with other changes of which evidence has been observed, such as the crystallization, the formation of concretions and the jointing.

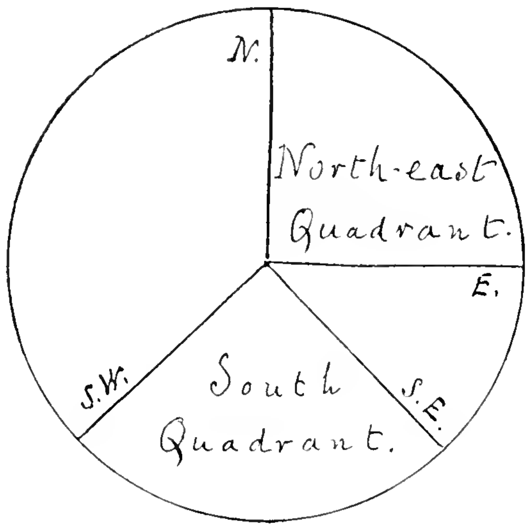
So far our observations of the older rocks have taught us something of their origin, and something of the remarkable changes which they have undergone since they were laid down in the sea, and among these changes we have noted that in the process of their elevation they have been forced up into highly sloping positions, and we have also observed in a general way that the slopes or dips are not all in the same direction. So varied are they, in fact, that our first observations in different parts of the island would almost lead us to despair of ever finding any system in the arrangement of these ancient strata; but if we go on collecting and mapping our information, order begins, by-and-by, to appear out of chaos, and the subject becomes one of absorbing interest.

CHAPTER V.

Arrangement of the "Blue-beach" Rocks.

After having accumulated a good many observations in regard to the dip of the blue-beach set of rocks, one of the first things we discover is that the varied dips admit of being grouped into two great classes, namely, in the first place, the dips which look to some point in the *southern quadrant*—that is to say, they are all included between southeast and southwest, and, in the second place, the dips which look to some point in the *northeast quadrant*—that is to say, they are all included between north and east. The accompanying diagram makes this distinction clear at a glance. The dips of the blue-beach rocks but very rarely pass beyond the limits here indicated for each class, and in continuing our studies we soon discover the great value of this classification. We soon find that one or other of these two sets of dips extends itself continuously over a considerable section of the island and becomes characteristic of that section, while by-and-by we are furthermore able to make out the boundaries between the various sections, and finally reach definite and most instructive conclusions.

Fig. 16.



Arrangement of the Rocks in the Western Oblong.

In commencing our observations for ascertaining the arrangement of the rocks of the blue-beach formation it is most convenient to begin with the *Western Oblong*, where the points above mentioned are illustrated in a clear way and on a large scale. The highly inclined strata whose edges cross the high-road to Frederiksted, and may be seen for a considerable part of the way between the works at Lower *Concordia* and those at *Wheel of Fortune*, have already been mentioned, and it was also pointed out in what an interesting way the presence of these strata is revealed, even where their edges are covered by road material or by soil and vegetation.

The special dip of the rocks seen along the piece of road above named—that is to say, a dip to south or south by east, can be shown to extend over a large part of the northwestern hills, but we soon find that it by no means extends over *all parts* of them; to the north and east another dip prevails, namely, a dip to east-northeast or points near to that. These latter dips are as prevalent over the northeastern half of the hill-block as southerly dips are prevalent over their southwestern half. It is, moreover, possible, by making sufficiently numerous observations, to ascertain approximately where the line lies that separates the two areas of different dips, and to show that it passes through the hills from about west-northwest to east-southeast, as shown on the accompanying sketch map.*

The discovery of the dividing line between these two areas of differing dips is sufficient to show that there is an order of some sort in the arrangement of the strata; but it remains to find out how that order is to be interpreted. What has happened to bring about such an arrangement of these rocks?

Upturned edges are found everywhere throughout both areas, but are most striking in the southern area, along the road near Concordia, already mentioned, where the abruptness of the edges is so conspicuous that we naturally ask what has become of the parts that must have been removed to show these remarkable edges?

It is not difficult to see that, given time enough, the wearing away of a large portion of the strata could be accounted for by the action of rains and the consequent rills and streams passing over the rocky edges, a destruction which, in fact, may be observed to be going on at the present day; but what forms had the strata in earlier times? Were they by gigantic forces broken off somewhat above the present edges, and if so, what forces broke them off, and what has become of the upper part so broken off? Or did they fold over, as their direction seems to hint, towards the north, the top or arch of the fold, in that case, having since been worn away? And if the rocks have been folded over, how can the southerly-dipping rocks be connected by a fold with the more northern rocks, which have a dip almost at right angles to theirs?

Had the two dips, as in the diagram (Fig. 18), been at right angles to the line of division which we have been able to lay down between the two areas, the explanation would have been very simple; the line in question would give the position of an *anticlinal axis*, from which the rocks slope away on each side, and it would only remain to explain the removal of the vast mass of rocks forming the upper part of the anticlinal curve.

In such case the whole story would be shown in a diagram such as that given below (Fig. 19), which represents a cross-section, lying about north-northeast and south-southwest.

* The reader who wishes to follow up this investigation in detail will find it dealt with in the Notes which follow these Chapters.

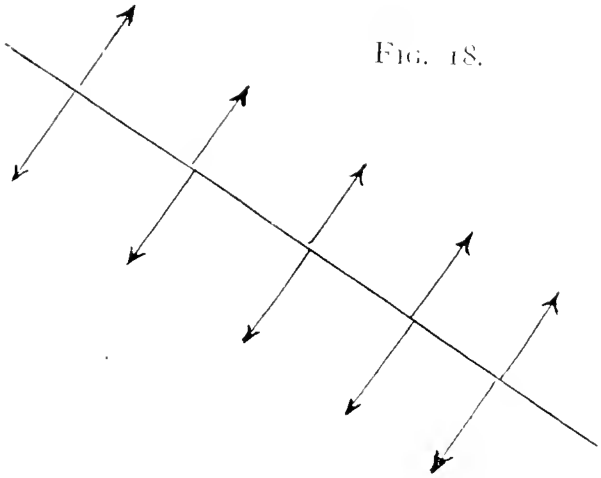
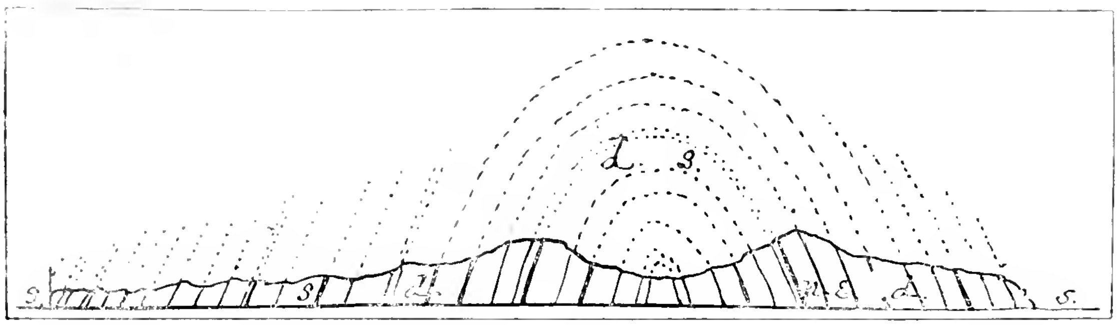


FIG. 18.

REFERENCE TABLE.

H. B.—Ham's Bay.
N. S.—North Side.
S. G.—Spring Garden.
M. V.—Mt. Victory.
A.—Annaly.
P.—Punch.
S. H.—Sprat Hall.
B. B.—Butler's Bay.
O.—Oxford.
O. G.—Orange Grove.
W.—Williams.
J. H.—Jolly Hill.
P.—Prosperity.
La G.—La Grange.
C. V.—Cane Valley.
W. F.—Wheel of Fortune.
C.—Concordia (Lower).
T. W.—Two Williams.
St. G. H.—St. George's Hill.
H.—Hogensborg.
S. G.—Stony Ground.
H. R.—Hannah's Rest.
W. B.—White's Bay.
Wh.—Whim.
G. H. Good Hope.
Ca.—Carlton.
P.—Prosperity (North).
N. S.—North Star.
C. B.—Cane Bay.
La V.—La Vallée.
M. S.—Mt. Stewart.
F.—Fountain.
Mt. E. R.—Mt. Eagle Ridge.
M.—Montpellier.
T. F.—Two Friends.
H.—Hermitage.
M. P.—Mt. Pleasant Colquohoun),
B. G.—Beck's Grove.
A.—Allandale.
G. P.—Grove Place.
U. L.—Upper Love.
J.—Jealousy.
M.—Mountain.
St. G.—St. George's.
P.—Plessens.
Mt. P.—Mt. Pleasant.
L. L.—Lower Love.
C. B.—Castle Bourke.
D. S.—Diamond School.
D.—Diamond.
P.—Paradise.
A.—Adventure.
E. G.—Enfield Green.
B. H.—Betty's Hope.
C. B.—Cooper's Bay.
E.—Envy.

FIG. 19.



S. S.—Sea level.
S. D.—Southwestern dipping strata.
N. E. D.—Northeastern dipping strata.
D. S.—Position of strata, assumed to have been denuded.

FIG. 17.

Anticlinal Axis and Synclinal Axis of the Northwest.

But the two sets of strata do not dip away at right angles to the axis but in a sloping direction on each side (Fig. 20), and we must ask, how is this to be explained? For an explanation we may fall back on an earlier result of our investigations. In our study of the limestone formation we saw that some of the lines marking the divisions between sets of limestone strata having different dips ran across other lines, indicating that the forces of elevation acted in two directions, crossing each other, though perhaps not exactly at right angles. We saw, for instance, that the limestones of the great Synclinal of the Central Slope do not dip at right angles to the axis but come down to it from the northeast on one side and from the northwest on the other, indicating a cross-elevation from the north.

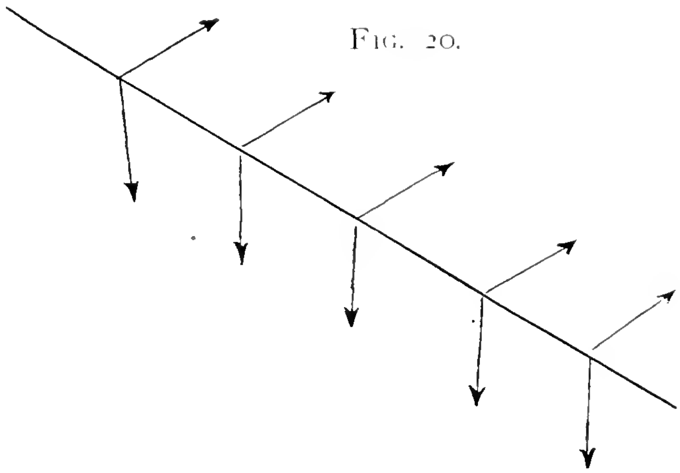


FIG. 20.

And, what has a more direct bearing on the case before us, we saw in regard to the anticlinal of the Mt. Eagle Ridge that as we followed the axis from the ridge across the plain and down the Barren Spot Valley the strata on either hand passed away to southeast on the one side and to south-by-west on the other, not by any means at right angles to the axis, but with a southerly inclination which could only be explained by supposing that there was also a tilting from the north. So in the larger case we are now considering, we have only to suppose that besides the pressure from the north-northeast which pushed up the ancient strata into a great fold (or into *folds*, as we shall see later), there has been another force acting from a line of elevation to the west which has given the sloping direction of the dips on both sides of the anticlinal.

When studying the Mt. Eagle anticlinal, the first which we met with in our investigations, we found that the case was well represented by an open book turned down on the table and then tilted from one end, and the same illustration will serve us in the present case. In fact, it seems that the illustration of the open book, simple as it is, gives the whole story so far as the directions of the dips over the areas in question are concerned, but it does not

illustrate the subsequent levelling down of the strata. The diagram (Fig. 19) may still be taken as roughly representing the anticlinal, if we remember that the strata slope partly forwards as well as to right and left; but the diagram would require some modification before it could be taken fairly to represent the facts; for the high dips, reaching sometimes even to reversions along the south side of the axis, compared with the more moderate dips along the north side, suggest that the curve of the elevated strata has not by any means been an evenly balanced one, but has been far steeper on the south side than on the north. After making this change there might still remain some subordinate folds in the strata which would lessen the height of the main curve. Yet it is evident that in any case it must have been very great. What an immense time must be allowed for the atmosphere, the rain and the streams to have worn away such vast masses of strata as this theory of their present arrangement implies! Even if we suppose these agencies to have had in remote times a much greater force than they have in modern days, yet we can only imagine that long ages must have passed during which these old rocks were being eaten down, to disappear later beneath the surface of the sea and to receive on their worn down edges the great deposits of limestone and marls which make up our newer formation.

But, to return to our observations. Following up the question of the extent of the northeastern dips, we find that while it extends eastwards, it is stopped short northwards by southerly dips, which, beginning at "Will's Bay," occupy the northern shores as far east as the estate St. John's and are renewed still further east across the Salt River and in Christiansted.

This change back to a southerly dip presents, however, no further difficulty. In coming to it we have merely arrived at a second great wave of the strata, and the line, which separates it from the area of northeastern dips already considered, is the line along the *hollow* of the wave, a *synclinal* axis, just as the former line of separation further south is thé line along the top of the wave or ridge, an *anticlinal* axis.

Thus we seem to have arrived at a satisfactory explanation of the arrangement of the older rocks in the western part of the island, and with the knowledge we have gained we may now proceed to a similar examination of those of the *Eastern Triangle.*

Beginning with the hills at Christiansted we observe that, with an exception to be noted later, the dips in the town and near neighbourhood are to southerly points. If we now take advantage of the great slit through the Christiansted hills, "Spring Gut," as it is commonly called, and pass through it from north to south, namely, from the "Parade Ground," east of Christiansted, to the estate Longford, we find as we ascend the valley, which at its highest point is about 400 feet above the sea-level, that, with one exception, a southerly dip prevails wherever the rocks show signs of stratification, but soon after we begin to descend on the south side, a striking change occurs, the dip passes in the space of a few yards from about southwest to east-by-north.

There is here, in fact, a fold in the strata. The rocks are hard beds of indurated clay, and towards the centre of the fold there are some slaty strata with a very rough cleavage. The soil and debris of the road-bank hide the junction of the two dips, but the slaty rocks at the two sides approach near to each other. Nor is this change in the dip confined to the narrow space here visible, for we find the layers lower down the hill dipping also E. by N. (at about 45 degrees), and at Longford, at the foot of the hills, we find in the road-trenches the rocky layers dipping at a high angle to E.N.E. It appears, then, that at the spot where the change was noticed, we have passed from a strip of country with dips within the *southern quadrant* into a strip of country with dips within the *northeast quadrant*. If the rule which we found to prevail in the Western Oblong can be applied to the Eastern Triangle, then the boundary between these strips should lie about west-northwest and east-southeast.

Numerous observations along the shore and on either hand show this to be the case, and enable us not only to mark down the northern limit of this strip into which we have come, but also its southern limit. This southern limit marks it off from the Waiter's Point district, in which we return to southerly dips.

Thus we have established that the key discovered to the arrangement of the rocks in the Western Oblong is also the key to the arrangement in the Eastern Triangle, at all events for its western part; that is to say, the rocks here, as in the northwest, have been forced up into folds by great pressure from about north-northeast. By following the same method of observing and mapping out the dips at various points we shall find that the arrangement prevails throughout the Eastern Triangle. The different anticlinals and synclinals will be found noted on the map prefixed to these pages, and those readers who wish to follow out the details of the observations will find them entered in the appended Notes.

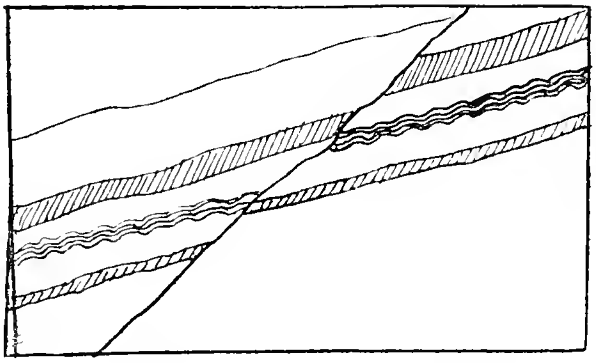
The large folds of the rock layers which have been so far worked out must be the principal, but considering that we cannot everywhere get access to the rocks, and considering that we occasionally, though rarely, meet with exceptional dips, it may be that other smaller folds occur. Contortions are not uncommon, and it may well be that there are some small folds also. Fuller observations of the rocks may discover these and thus make some modifications of the present results necessary.

CONTORTIONS.

Reference has been made above to "contortions" as being "not uncommon"; at the same time it must be noted that these twists in the strata are not as frequent as we might suppose when we think of the immense pressure there must have been on the rocks to force them up into the great ridges and hollows which we have just studied. Examples of contortions may be seen at the Fort in Christiansted, at Fort Augusta at the entrance to the harbour, and

in the cliffs beyond Princess, where the writer has ~~a~~ seen a bend in the strata resembling a large S. The most curious case met with by the present writer, however, is to be seen at Ham's Bluff, where some very thin sheets lying close together in a broader band have been squeezed up into small ripples, the layers above and below remaining unaffected. This interesting result is shown in the diagram (Fig. 21), and may be explained by supposing that the waved layers

FIG. 21.



Small contortions in rocks at Ham's Bluff.

began to stiffen, for some reason to be sought in their composition, earlier than the adjoining material, so that while the latter yielded to the squeeze the former could only accommodate itself to the reduced space by falling into folds. It is doubtless the same necessity which has given rise to all contortions, but it is seldom that we meet with so compact and clear an illustration of it.

SUMMARY.

To sum up this question of the folding of the "blue-beach" rocks, it will have been seen that in both the Western Oblong and in the Eastern Triangle we possess clear evidence that the ancient strata of the island have been pushed back into folds by some tremendous force acting from about north-northeast, and that the effects of this force have been modified by a force acting crosswise to it. We have been able to mark down approximately the positions of the lines which mark the crests and the hollows of these folds—that is to say, the folds that have been produced by the force from north-northeast, and in this way we have come to some idea of how the island's strata are now arranged. The marvel of the removal of the vast masses of the crest of the folds or waves so as to show everywhere the edges of the strata, still remains, a marvel which, after all, is only slightly lessened by our knowledge of the power of the sea and the rains to plane down the land surfaces.

If we now pause to summarize what we have so far learned about the older of the two formations of our island, we find:

1.—That it is essentially different from the younger group, being substantially a clay formation, while the latter is a lime formation; the one material a

product *ultimately* of igneous rocks, the other extracted from sea-water by living agencies.

2.—That, although ultimately in the main a product of igneous rocks, it has been laid down in the sea in regular strata.

3.—That the supply of material has apparently been so abundant and so continuous as to allow only of a small contemporaneous deposition of limestone by the sea creatures, yet that there are, nevertheless, some scanty remains of such limestone deposits, and that these contain distinct evidences of their origin in the sea.

4.—That after their deposition in the sea the strata have been greatly altered by heat and water, so that they have for the most part taken a crystalline form.

5.—That they have also undergone some other remarkable changes, such as attaining in many of the beds the *variolitic* character, the tendency to split in certain directions, known as *jointing*, and especially in this connection, in so far as the slaty rocks are concerned, the acquisition of *cleavage*.

6.—That while these changes were going on, or at all events since the deposition of the materials, the whole mass of strata was forced up by pressure, from about north-northeast, into parallel waves or ridges, whose form has again been affected by pressure crosswise to the above-named direction.

7.—That the crests of these waves were eaten away through a vast period of time by incessant attacks from the sea along the land edges and by the rains and the consequent streams over the surface, so that at last they were planed down, perhaps so far even as to leave an approximately level surface, presenting everywhere the edges of the strata.

8.—That the land so planed down then sank under the sea and received on the upturned edges of the strata, during another vast period of time, the deposits which make up our limestone and marl formation.

9.—That having received these large deposits on the upturned edges of the strata, the whole mass was once more forced up, bringing them above the surface of the water along with it.

10.—That both formations have since then, and partly also during the lifting process, been acted on by the sea and by the rains and streams, so as to have their surfaces carved into the forms we now see, a subject, however, which has so large a scope that it will be well to reserve it for separate study.

Before proceeding to that subject we may take a brief look at the igneous rocks which have been intruded from below into the older formation but have never, so far as is known to the present writer, reached so high or been intruded so late as to show themselves in the newer or limestone formation.

CHAPTER VI.

The Igneous Rocks.

Our examination of the stratified rocks of the Clay Formation has shown us that a large proportion of them are crystalline, and that the change has been in many instances carried so far that the marks of stratification are not brought out by weathering, and in these cases it is only the gradual passage of the rock from the stratified form to the unstratified form which convinces us that the latter is in reality a sedimentary rock like the former, only that it has undergone a higher degree of alteration.

Occasionally, however, we meet with some form of crystalline rock which has plainly been thrust through the stratified rocks, and it is in this case evident that the former has been in a molten condition when it was thus forced through the strata.

The igneous rocks thus forced through the strata are frequently met with in the form of walls of greater or less width, technically known as "dykes." Such dykes are to be seen here and there in our older formation. The most accessible example from Christiansted is a dyke in the quarry immediately east of the town on the south side of the high-road. The stratification of the rocks in this quarry is very plainly marked. They dip at about 45 degrees to the south, and the dyke cuts them through in a wall about 6 to 8 feet thick. Its length lies northwest and southeast, and it slopes at about 60 degrees to southwest. The rock in this dyke is slaty blue or grey in colour, is speckled with distinct crystals and is very hard. Another good example may be seen at Fort Augusta, at the entrance to Christiansted harbour. The stratified rocks at the Point are in dark slate-coloured and brown layers alternately, all much contorted, but mainly dipping at an angle of about 30 degrees to south. Through these rocks a broad dyke passes across the Point north and south showing itself in the cliffs on both sides. In the yard of the Fort, which at the present writing is bare of gravel, the rock of the dyke may be very plainly seen in contact with the beds of the stratified rock, which it has bent backwards, so that they form as they cross the yard a succession of arches facing on the one side to southeast the other to southwest, and in the middle towards the south. On the north side of the Point may be seen embedded in the igneous rock a piece of stratified rock torn off doubtless by the flow of the latter as it broke through the strata.

There is another good example of a dyke in a "gravel pit," or quarry, on the northeast side of the hill on which "Upper Love" village stands. The rocks here are in regular layers, dipping at a high angle (about 60 degrees) to the east. The quarry looks east, and the dyke passes along its face in a waved line from south to north. The dyke is about eighteen inches wide, is much decomposed on its exposed edge and appears to slope downwards to the west. It has been broken through by small faults (about six inches) in two places, faults which obviously must have been caused by movements later than the

formation of the dyke. The above examples of dykes may be sufficient to illustrate their character, the student will readily find others; but besides appearing in the form of dykes, the igneous rocks appear sometimes to have been thrust up in considerable masses. The rocks at the summit of Mt. Eagle appear to be of this kind.* At the cattle pen at the estate "Bugby Hole," a great mass of cream-coloured rock, inclining to red, may be seen, which appears to be the same rock as is so abundant along the south side of St. Thomas and is called by Professor Cleve *felsite*. Around the works and the residence at the estate Annaly, a rock appears which weathers to a white clay and, consequently, has in some parts the outward appearance of a marl. It is a massive unstratified rock of a very pale green colour and has a semi-translucent appearance. It is presumably a felsite.

At the bank by the side of the high-road at "Grange" and also on part of the estate "Beeston Hill," there is a highly decomposed igneous rock which contains a quantity of yellow mica in shining specks. A similar rock is found at the estate "Hermitage." The mica is probably coloured by a trace of gold, at all events the writer was shown, many years ago, a sample of yellow mica sand which had been sent from St. Croix to London for expert opinion, and which was reported on as containing gold, but not in any payable quantity.

Among the stratified rocks which are seen on "Blue Mountain,"† an igneous rock has forced its way, and near to the summit of the mountain has partly broken up the strata so that the fragments of these are seen embedded in the intruded rock. This rock is fine-grained, grey in colour, and externally resembles grey granite. It probably belongs to the same class of rocks as that mentioned in the following paragraphs.

* The following notes were made by the present writer after ascending to the summit of this hill:

"Ascended from 'Hermitage' to lower part of the ridge and then proceeded northwest and afterwards west to the summit of Mt. Eagle. The whole slope of the ridge is covered with loose blocks and smaller pieces of stone. Most of these show clear traces of stratification in narrow brown and whitish brown bands. Mingled with these there are, however, many pieces of igneous rock, characterized by numerous and rather large felspar crystals [probably felspar-porphyry]. The summit of Mt. Eagle shows no stratification, but appears to be a compact or very fine-grained crystalline rock of igneous origin. The rock is split by numerous cracks [joints], for the most part vertical and having the direction of east and west."

† The following notes were made by the writer after ascending the ridge, as mentioned in the preceding note:

"Passed along the ridge [Mt. Eagle Ridge] to Blue Mountain. Ascending towards the summit found traces of stratification on the way up, dip east-southeast, at a high angle [70 to 75 degrees]. At summit found same dip continued. The rocks here are in bands of a brown, whitish brown and light-blue or slate colour. In one part the rocks appear to have been entered by greenstone and the strata seem to have been broken up by it and the pieces mixed with it. The greenstone is very fine-grained and is externally grey. The stratified bands are mostly very thin and recall the rocks at 'Buck Island' and some of those about 'Judith's Fancy'.

"Near the summit [of Blue Mountain] on the northeast there is a protrusion of greenstone which weathers light grey and *looks* much like grey granite. It is split by joints running north-northeast and south-southwest at a high angle and by others at right angles. These joints are so regular that it is difficult to resist the impression that the rock is regularly stratified, yet the crystalline structure is perfect and the composition of the two or three layers exposed seems to be identical. It is probably an intrusive sheet of greenstone. This rock exhibits some beautiful hornblende crystals on the exposed surface."

At the estate "Southgate" and the neighbouring islet of "Green Kay," there is a great quantity of a grey rock which, in appearance, resembles granite, being composed of white crystals with black oblong crystals among them. It is, however, different from granite, for while that rock consists of the minerals felspar, quartz and mica, the rock at the places named consists of felspar and the dark mineral hornblende. On Green Kay, both the black and the white crystals attain in some places an unusually large size. The rock is called greenstone or *diorite.*

Professor Cleve mentions the occurrence of diorite at Southgate and Green Kay as well as elsewhere among the islands, and has some interesting comments on the rock. He regards it as altered from the sedimentary rocks by heat to such an extent that it has in some parts, but not everywhere, become actually molten. He arrives at this conclusion from having found it in the Virgin Islands, both interstratified with the other rocks without any sign of intrusion, and also filling cracks in the surrounding rocks, in which latter case it has evidently been intruded in a molten state.

Such a conclusion is probably true of at least some other intruded rocks. There is nothing to show that they come from any considerable distance below, and it may well be that they are sometimes only the stratified rocks of the neighbourhood which have actually been melted and thus made capable of passing among the other rocks, following the direction of least pressure.

These rocks which we have seen to be thrust in among the stratified rocks of our older formation in masses and dykes, though of volcanic character, are not, strictly speaking, volcanic rocks, that is to say, they have not been thrown out by volcanoes. So far as the present writer is aware, there is no evidence in any part of our island of volcanic outbursts through the rocks we now see. There is a strong probability, it is true, that the existing layers have been formed from matter thrown out by volcanoes, either directly into the sea or on to a neighbouring land from which they were washed into the sea, but there appears to be no evidence anywhere of a crater or of the piling up of layers of volcanic ash and cinders. If there were volcanoes at any time on the site of what is now Santa Cruz, they have long ago been swept away in some of the many changes that have passed over the solid structure of this beautiful little land of ours, and no trace whatever of them remains.

At the same time the rocks in question, though not likely to have been actually volcanic, consist of the same substances as make up the volcanic rocks, and, as already noted, they have been in a molten condition.

Rocks of this class are often spoken of under the general name of "trap," an old-fashioned name but convenient for an amateur, since its use avoids the necessity of any closer naming of the kind of rock, a task which must be left to experts. The name "trap" is derived from the Swedish "trappa," a stair, and was applied to this class of rocks because they are sometimes found to be arranged in successive steps, formed from outflows whose spread became less and less as they were successively pushed up amongst the strata, lifting the

upper beds. This formation of layers is especially conspicuous in the member of the Trap group known as basalt, a hard, fine-grained black, sometimes grey, rock, found in many parts of the world, as, for example, in the north-east of Ireland and southwest of Scotland. It is over a layer of basalt that the Zambesi in South Africa flows as it approaches the famous Victoria Falls, about which it was formerly supposed that the wonderful cross-chasm into which the river pours was produced by a great convulsion of Nature, but in regard to which a recent observer has shown that both the chasm and the zig-zag gorge, through which the river makes its way to the lower plain, have been formed by the wearing action of the river itself, whose waters have cut down through the basalt, the flow having followed great cracks which pass across it. There do not appear to be any extensive overflows of basaltic or other trap rocks in our islands, nor does basalt seem even to exist here, for the hard black fragments which are sometimes found in the blue-beach conglomerates, especially in St. Thomas, are spoken of by Professor Cleve as "dark porphyry or felsite."

Questions as to the names and characters of the igneous rocks are, however, for professional geologists rather than for amateurs, who, unless they have special knowledge, must be satisfied with the more general results of their observations.

CHAPTER VII.

Minerals.

The study of minerals is an extensive subject in itself, nevertheless it is not difficult to acquire a few simple facts about them which will add interest to our observations when examining the various rocks of our island.

What is a mineral? That is a question not so easy to answer as may at first sight be supposed. In every-day language anything found in the solid part of our earth may be called a mineral; but in a scientific sense the word has a more restricted meaning. The following definition and comments are taken from the introduction to Nicol's Elements of Mineralogy: "In the strictest sense, a mineral species is a natural inorganic body, possessing a definite chemical composition and assuming a regular determinate form or series of forms. This definition excludes many bodies often regarded as minerals: as, all the artificial salts of the chemist, all the inorganic secretions of plants and animals, all the remains of former living beings now imbedded in rocks. Some substances originally organic products have indeed, by common consent, found a place in mineral systems, as coal, amber, and mineral resins; but this is a departure from the strictness of the definition, and in most cases had, perhaps, better have been avoided. So also some amorphous substances, with no precise form or chemical composition, as some kinds of clay, have been introduced into works on mineralogy, but we believe often improperly, and with no beneficial result. Aggregates of simple minerals, or rocks, are likewise excluded from this science, though the various associations of minerals, their modes of occurrence, and their geological position, are important points in the listing of the different species."

The same author, in the beginning of his first chapter, in which he treats of the forms of minerals, says: "Mineral substances occur in two distinct modes of aggregation. Some consist of minute particles simply collected together, with no regularity of structure or constancy of external form, and are named *amorphous*. * * * * The other class have their ultimate atoms evidently arranged according to definite law, and are named *crystalline* when the regularity of structure appears only in the external disposition of the parts, and *crystallized*, when it also produces a determinate external form or a *crystal*."

In the limestone and marl formation of Santa Cruz and in the few limestones of our oldest formations we may find a partial illustration of the above. Frequently in the cracks of the limestones and in the small hollows in fossil corals we may see an abundance of small crystals of carbonate of lime, crystals which are known as calc-spar or calcite. The same substance is abundant in an amorphous state (that is to say, without definite form), in the numerous concretions of some of the beds and also in some of the more compact beds in their entirety. The same *crystalline limestone* is, however, reserved for those sparkling limestones known as marble, which have been produced in the earth by

great heat and pressure from ordinary limestones, a fact which has been established by the artificial conversion of chalk into marble under pressure in a blast furnace. It does not appear that our Santa Cruz limestones, even in the older formation, have been placed under like severe conditions with the true marbles. Professor Cleve calls these beds in our older formation merely "compact limestone." In writing of the rocks in the smaller islands around St. Thomas, he says, however, that "Congo Cay is a ridge of beautiful, hard and crystalline limestone or marble, of a bluish gray colour and parallelopipedic structure." He also mentions crystalline limestone as found in St. John, between Brown's Bay and Mary's Point, in Tortola, in Ginger Island and in Great Hatch Island. From which it appears that by including our near neighbors, islands which indeed, from a geological point of view, are included in our system, we may find illustrations of carbonate of lime in each of its three forms, *amorphous*, *crystalline* and *crystallized*.

In connection with this very abundant component of our rocks there is a point which, though somewhat obscure, is of such great interest as to be worth a few lines being devoted to it. The removal of shells and corals imbedded in the rocks so as to leave hollows still showing their forms, must strike every observer as a very remarkable fact. Why should these objects have been dissolved out and have disappeared, while at the same time the mud in which they were imbedded, and which consisted mostly of similar material in a finely divided state, remains untouched by the dissolving agent? This is a question for the mineralogist to answer, and it is answered by Professor James Dana in his Manual of Geology.

Carbonate of lime, he tells us, forms two distinct minerals, *calc-spar* or *calcite* and *aragonite*. The former mineral, as we have seen, is common in St. Croix, but the latter does not appear to be found here in its crystallized form, though, as we shall presently see, it must be fairly abundant. Aragonite takes its name from the Spanish province of Aragon, where, as well as in some other parts of the world, it is found in great beauty. It is crystallized in thin prisms, hence sometimes called *needle spar*, and is rather heavier than calcite. Professor Dana says that "shells, while consisting generally of calcium carbonate, often have a large part of the material in the *aragonite* state; and hence aragonite is present through most uncrystalline limestones."

Further on, in his notes on "Chemical work," the Professor writes: "If the fossils of a limestone are made of calcite and aragonite [the latter the prismatic calcium carbonate], the aragonite portion is taken away—a fact first reported by Sorby. Shells of the kind referred to are those of the genera *Pinna*, *Mytilus*, *Spondylus*, *Patella*, *Fusus*, *Purpura* and *Littorina*, in which the inner pearly layer is aragonite, and the outer calcite. The shells of most Gastropods and Cephalopods are aragonite; and corals, including the millepores, are mainly so; while shells of Rhizopods, Echinoderms and Brachiopods consist of calcite."

Professor Dana further remarks: "When the minerals aragonite and cal-

cite are present together in a limestone, the first effect of metamorphic action is the conversion of the aragonite into calcite." From which we may infer that in those parts of our limestone formation where the fossils have disappeared the aragonite has disappeared by alteration into calcite and has been added to the mass of the rock in this form; whereas in those parts where the fossils still remain there is some aragonite yet present in the rock, justifying the earlier remark quoted, in which aragonite is said to be "present through most uncrystalline limestones."

The present writer has not been able to find any rule for the occurrence of limestone fossils in our island in the two forms mentioned—namely, as solid fossils and as casts. A close study of the rocks and the fossils would probably throw some light on the subject and would repay the reader who may have time and opportunity to follow up the subject.*

Quartz is a well-known mineral and occurs abundantly in the older of our two formations. It is easily recognized by its great hardness, in which quality it is exceeded by only a few minerals. Commonly we can see that it has filled up cracks in the rocks, and hence appears as white veins running irregularly through them, while it sometimes forms six-sided crystals in the innermost parts of the veins.

Flint is nearly the same substance as quartz—that is to say, pure silica, but is not, so far as the writer knows, found in St. Croix. It is in quartz veins that gold is obtained in many parts of the world, but it does not appear that the quartz veins of any part of St. Croix contain that precious metal.

As already mentioned, the chemical substance which forms quartz is silica, which again is a compound of the elements silicon and oxygen. Quartz has been deposited from silica in solution, and in some parts of the world it has been deposited in large transparent crystals of great purity and beauty; it is then known as rock-crystal. Many beautiful stones used by jewellers, such as amethyst, topaz, cornelian, jasper, etc., are only coloured varieties of quartz. Our own island does not, however, appear to contain more than the simplest forms of the mineral.

Felspar, of which there are several kinds, is a mineral that may often be seen as small white crystals in our older rocks; and in the rocks of the islet called "Green Cay" it is seen in crystals of unusually large size. This mineral, though not as hard as quartz, is still so hard that it is with difficulty scratched by the point of a knife. Its chief constituents are silica and alumina. Felspar occurs in an uncrystallized form in most of the older stratified rocks of the island and in the igneous rocks. When decomposed it forms clay, sometimes *white* clay, but more commonly *brown* clay—that is to say, it is coloured by iron. Hence, it is from the felspar of the rocks that the clay which forms a great part of the soils and subsoils in many parts of the island is derived.

* The reader who may wish to verify the quotations from Professor Dana's Manual of Geology will find in his index, under Aragonite, references to the pages from which they are taken.

Hornblende is a dark-coloured, glistening mineral, very common in the older rocks. Professor Cleve remarks that large crystalline masses are found near Santa Cruz in the small Green Cay.

Mica is a mineral that crystallizes in thin sheets, which in some countries are sufficiently large and transparent to form to some extent a substitute for glass. In our own island the mineral is found in tiny flat specks disseminated through some of the rocks, as, for example, near Grange and Beeston Hill and near Hermitage. In some places it has been sorted out from the other materials by the running streams, and may be collected in some quantity. Many years ago the writer was shown a sample of such mica sand, which, on account of its yellow, shiny appearance, had been sent to a London assayer for examination, and was pronounced by him to contain gold, but in too small proportion to make the sand of any value.

Magnetic Iron Ore. On the sand of the shore near Fair Plain a black sand may sometimes be seen in patches, and on examination of the particles they proved to be small crystals of magnetic iron ore. Here it is the motion of the waves on the beach which sorts out the iron grains in this peculiar manner; but like the grains of mica sand, these particles have been derived from decomposed rocks of the Indurated Clay formation, and have been brought down by the streams. This is a mineral which is found in many parts of the world, and in some places is very abundant. As is well known, Mr. Edison has large works in New Jersey for crushing certain rocks which are abundant there and for separating the iron grains by sets of powerful electro-magnets, in front of which the powdered rock is dropped in a continuous stream, the iron grains being drawn inwards as they pass the magnets and so falling in a separate heap. Afterwards the material is made into bricks for transportation to the iron works where it is to be manufactured.

The minerals to which attention has been drawn in the above notes are those which will commonly be noticed by the amateur while examining the rocks of St. Croix.

So far as is known to the present writer, no valuable ores occur in the island, which is not the same thing, however, as saying that there are none. The writer, to say nothing of the rock exposures which he has not examined, is not a mineralogist, and it is possible that he may have passed by some indications that may be recognized by an expert later. Molybdena and ores of copper are found in the neighbouring island of Virgin Gorda, and the writer has been told that galena (lead ore) containing traces of gold and silver has been found in one of the St. Thomas Cays. Gold is also occasionally found in the beds of some of the Porto Rico streams. With all these indications in the neighbourhood, it may well be that some valuable metallic ores occur in St. Croix. If ever found, the question will still remain whether they are worth anything from a commercial point of view, a question which in the instances named has been so far answered in the negative.

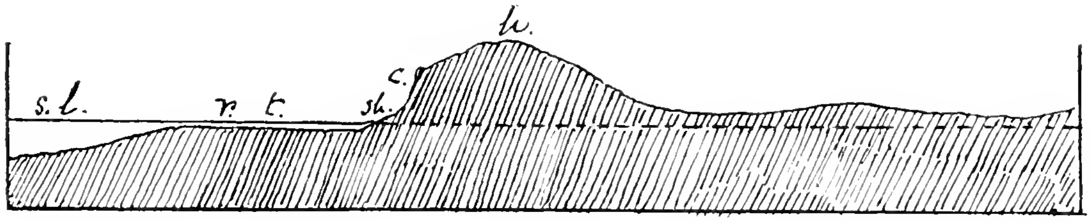
CHAPTER VIII.

The Sculpturing of the Island.

At the beginning of our study of the island we saw that the outline consisted of three parts, a narrow triangle to the east, an oblong to the west and a sloping neck connecting these two, but we did not then go further into details.

When we now proceed to examine this outline more fully, one of the first things that strikes us is that there are many projecting points or capes, and on examination these points most often prove to be rocky, though not always so, for we find conspicuous examples to the contrary in Sandy Point at the southwestern extremity of the island and at Krause Point on the south shore, both of which, except where the sand has been converted into rock, appear to consist of loose sandy material. As a rule, however, the capes are rocky. And we further notice that most of these rocky headlands are small hills, whose seaward slopes have been cut away into cliffs by the wearing action of the waves.

Fig. 22.



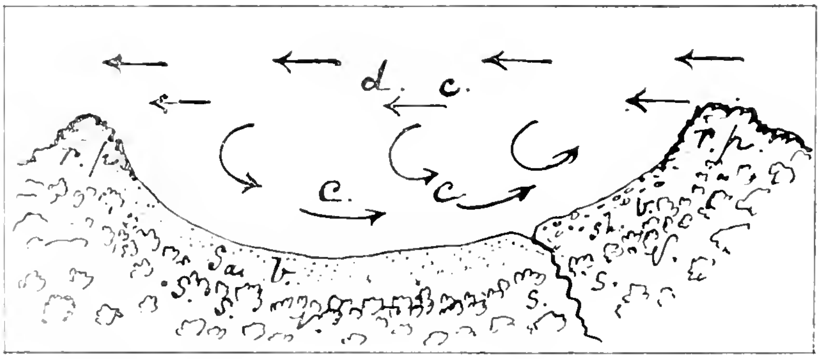
h.—Hilltop. s.—Shore. s. l.—Sea level.
c.—Cliff. r. t.—Rocky table.

At the foot of the cliff the sea has, moreover, ground down a rocky table or platform, which now projects from the shore below the level of the water. How were these platforms made? The water alone could hardly have carved them out of the solid rock, but we must remember that the water is continually carrying sand and the stones previously broken out of the cliff backwards and forwards over the rocky table, and that these can and doubtless do grind down the surface. It sometimes happens, too, that off shore at such a point we find that a small reef has been formed, its foundation being, in all likelihood, a still earlier remnant of the projecting point. Between the capes there are bays which sweep round in concave curves from cape to cape. The sandy shores of these bays are mostly backed by banks of debris from the hills, and there is, apparently, nothing to prevent the sea from carrying off both sand and debris and so pushing the curve of the bay farther and farther back. As, however, these curves remain pretty constant, it is plain that the sea must be prevented by some fixed law from doing this; and the law is not difficult to discover.

The diagram (Fig. 23) represents two rocky points with a sandy bay between them. Outside the points the general east to west current runs. If the sandy shore were in a straight line with the points, the current would soon remove a part of the sand and cut the shore back into something like the curve indicated in the diagram, and we find that it has actually done so. But why does it not continue to cut it back? Why does the outline of the bay not recede still farther? It is because the current cannot penetrate any farther, but creates a *counter-current* in the bay, a current which, on its inner side, is so sluggish that it would quickly drop any sand or mud which it might have seized on.

An interesting proof of the existence and effect of the counter-current may sometimes be seen when a small stream runs into the water of the bay and brings down pebbles from the surface debris, in which case the pebbles are deposited, not on the leeward side of the stream's mouth, as we might expect, but on the windward side. They move *against* the direction of the general current under the influence of the counter-current. This is shown in the diagram, which fairly represents an actually existing bay on the north shore of the island. Storms may make small temporary changes in the curve of such a bay, it is true, but when the usual daily conditions set in again, the shore quickly regains its former outline.

Fig. 23.



d. c.—Direct current.
c. c.—Counter current.
r. p.—Rocky points.
sa. b.—Sandy beach.
sh. b.—Shingly beach.
s. s. v.—Seaside vegetation.

Only the wearing back of the rocky points which protect it can cause the sandy shore of such a bay to recede inland. But this wearing back of the rocks is undoubtedly always in slow progress, the rocky protectors are gradually driven back and the sandy shore must slowly recede with them. This result is occasionally recorded by the beach limestone remaining as an evidence of the distance to which the shore has been recently pushed back; a good instance of which is seen in Christiansted harbour, between the Fort and the mouth of the Lagoon, where a strip of shallow water, twelve feet or more in

width, intervenes between the present sandy shore and a small reef of beach-limestone, which marks a former shore-line.

Another evidence that the rocky points cannot for ever protect the shores of the bays is found in the low cliffs formed of debris which in many places has been washed from the hills by the rains, cliffs which show by their abruptness that an encroachment is being made upon them, as, for example, at Great Pond, at La Vallée, and at Ham's Bay.

Thus we perceive that the sea is continually eating away the land at its edges, and only requires time to bring it all down beneath the sea-level.

Even the reefs, which are really magnificent protectors, because covered by living coral, which is always able to maintain itself against the waves by new growths, and even in case of the gradual subsidence of the bottom can keep the reef by such growth nearly up to the level of the water, yet these wonderful reefs even cannot save the land from ultimate destruction, for the continual currents and the occasional storms can work a way inside them and may ultimately leave them isolated out at sea, as most likely has been the case with the reefs which we find a mile or two out at sea along our southern coast.

Sandy Points, like the two above-mentioned exceptional cases (Krause Point and Sandy Point), can only exist under special conditions, the trend of the coast and the existence of extensive reefs may direct the currents in such a way that the sand is deposited, instead of being carried off; but in the long run these special conditions must be changed and the protected sandy points will be removed as surely as are their rocky neighbours.

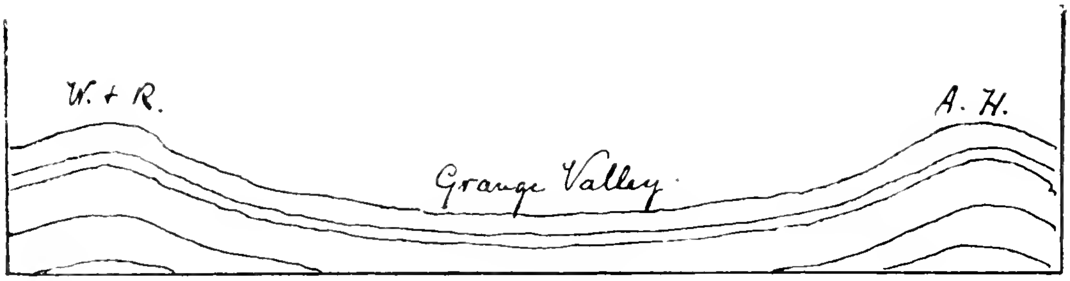
It appears, then, that granted time enough, the land could be eaten away by the sea alone, but when we study attentively the agents that are at work on the surface of the land, we shall see that if a considerable part of the wearing away is due to the sea, a far greater part appears to be due to the rains and the streams.

It is certain that the material which makes our present land has not been put down in the sea in the form of hill and dale as we now see it, but that this form has been given to it since its upheaval. Let us take, for the sake of illustration, the hills at Anna's Hope and at Work and Rest, on opposite sides of the Grange Valley (Figures 24 and 25). When we examine the strata in these hills we do not find them taking the slope of the hillsides; but we find that they come out of the hillsides as though they were once continuous across the intervening valley, and the more we examine the question the more convinced we shall become that such really was the case.

It seems, then, that the valley has been carved out of the uplifted strata, and the hills are what is left behind. From this point of view it is the valleys, and not the hills, which are the positive features in the landscape, and after we have understood the facts connected with the elevation of our island, it is the valleys which we must study first if we wish to know anything of the sculpturing of its surface.

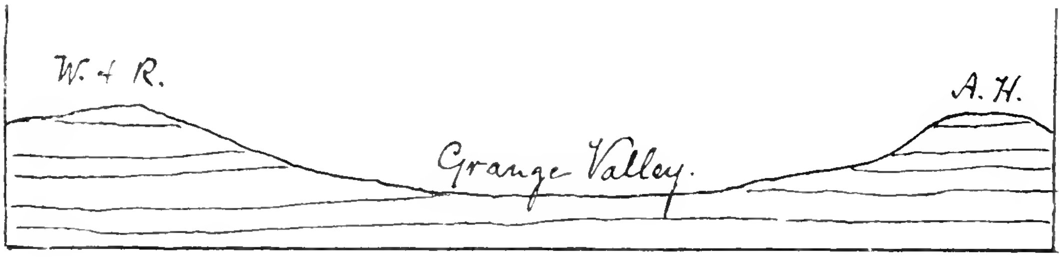
First, then, let us ask by what tools the excavation of the particular valley

FIG. 24.



How it is NOT.

FIG. 25.

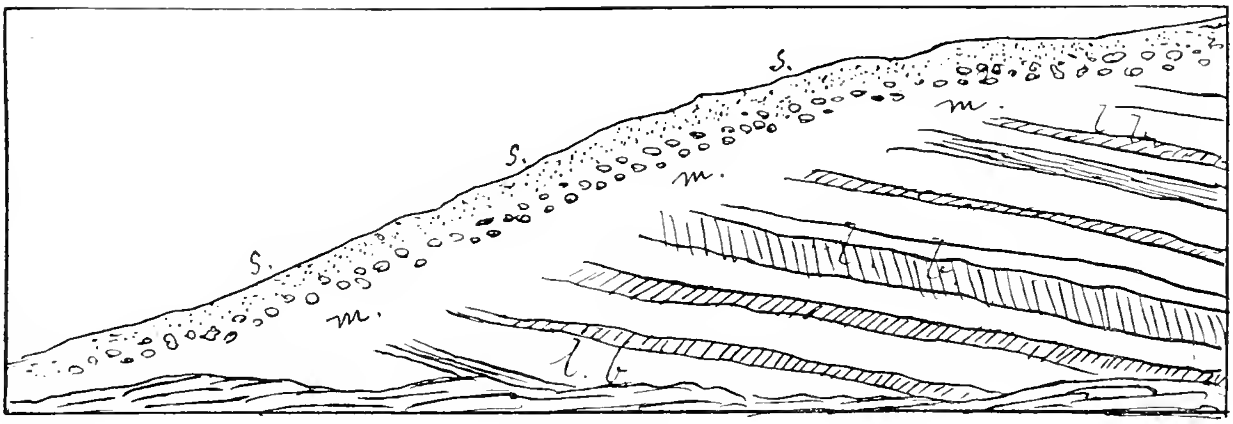


How it is.

we have selected to examine has been effected. Along the lowest line of the valley we find a small stream running, which starts among the hills at the back af Christiansted and runs into the sea, near the estate Hope. If we examine the sides of the watercourse along which this stream runs, we see that it is mostly bordered by steep banks, and that these, first in one part and then in another, are being cut down by the water accumulated in the brook after heavy rains, so that the material which forms them is removed farther on and lodged there and ultimately carried out to sea. It seems, at first sight, impossible that this little stream can be the chisel which has carved out the wide valley through which it runs. Neither could it have done this great work without assistance, but when we notice what happens over the whole valley after a heavy fall of rain, we shall see that a number of tiny rills run down the sides of the valley from all parts, everyone of them muddy, and everyone of them, therefore, showing its power to remove a modicum of the solid land and lodge it lower down, ultimately to reach the sea. Every other valley in the island shows the same thing. Let us look, for example, at the three or four small streams that come down during heavy rains from the hills lying south of Christiansted; we find them all carrying down mud, sand, and sometimes even stones, to the sea. After such a rain the harbour is discoloured for a long distance from the shore. If we then look up at the forms of the valleys from which these streamlets run and from which they are carrying away all this material, we see that the main valleys all have numerous smaller valleys which have been cut out of the

shoulders of the hills, and these again have still smaller valleys leading into them, so that during rains the hills are drained by a multitude of small rills, each of which is a tiny chisel, cutting the valleys deeper and deeper, and slowly, but continually, lowering the slopes. It is to the action of such tools that we owe the valleys. And while it is true that we owe the hills as masses to the elevating forces, it is nevertheless mainly to the action of rain that we owe their special forms, for the forms of the valleys decide that of the remaining stuff which constitutes the hills. Nevertheless, the nature of the stuff itself has much to say in deciding how the surface is carved out, as we shall presently see. For there is another force at work, preparing the rocks for removal, and that is the chemical action of air and water in breaking up or decomposing the rocks, and the rate of this process varies greatly, according to the nature of the rock. Water and air find their way into the rocks through the cracks, which, as we have already seen, abound in most kinds, and gradually change their character. Finally, a soil is formed, generally full, however, of the small fragments which result from the multitudinous cracks in the solid material, for the most part, therefore, gravelly in the blue-beach formation, and often filled with small limestone fragments in the marl formation. Examples of both kinds may be seen in the upper parts of gravel pits and marl pits in many parts of the island. The soil thus formed is further divided by the roots of the

FIG. 26.



A MARL PIT.

l. b.—Limestone beds.
m.—Marl (altered edges of the beds.)
s.—Soil (covering a layer of limestone fragments.)

countless plants which grow in it, and, dying in it, leave their decaying roots to darken the colour of the soil with the carbon which the plants have collected from the air. It is from these soils, of various degrees of poverty or richness, that the little chisels running down the hillsides and along the bottoms of the valleys scoop out the modicum of the island which each is stealing

to carry lower down the slope and ultimately to the sea. We see that if such a process is continued for ages it must reduce the general level of the island. We also see that the process must be very slow, but must be especially so where the rock is very hard and offers great resistance to the preparatory decomposing action of the atmosphere. The points and lines, or the areas, where such hard rocks exist, must come gradually to stand higher than the softer material which surrounds them, and thus it is not difficult to understand that the forms of the valleys, and consequently of the hills, is a good deal dependent on the nature of the rocks.

Of this general truth we may occasionally find striking illustrations. For example, when we drive past the residence of Diamond and Ruby we notice, as we ascend the rising ground from the direction of Christiansted, that there are many hard blocks of limestone lying by the roadside. We do not see, in the cultivated fields, where these blocks have come from; but if we take the road over Carrawall Hill and cross the same rising ground a short distance to the south, we see that a rather thick layer of hard limestone is cut through for the road where it nears the top of the rise. Here we see what it is that has given origin to the large limestone blocks just mentioned, and what it is that has protected this rising ground from the destructive action of the waters coming from eastwards; and we see that the whole rise which, as a matter of fact, *crosses* the slope of the strata and the consequent general direction of the drainage, owes its origin to the existence of this hard bed. In the same connection it may be noted that the tops of the hills often show such hard rocks that we can hardly conceive of their ever being worn away, yet the roughness of their gray lichen-covered sides and their rounded angles give us a hint that, though they may hold out for many centuries, they, too, must finally give way to the destructive forces. Sometimes on the hillsides we meet with large isolated blocks of stone of extreme hardness, whose form shows us that they have been detached from layers of rock higher up the slope, and we wonder how they can ever be worn away; but we, perhaps, find some of them still lower down the hill, and we perceive that they must have been removed from above. But how? Some day, after a storm perhaps, we get a lesson on this point; a large block that we remember to have noticed on the upper side of a road, for example, has slidden down and now partially blocks the road. This compels our attention, and we reflect that these isolated blocks must in all cases be moving down the hillside in this way. Every heavy rain removes something of the soil and the gravel on which the block is resting, and by and by it slides farther down, till finally it will reach the nearest watercourse. In such a watercourse among the hills we may often find some of these large blocks from the slopes; and what happens to them there? Why, that every flood in the watercourse rolls along, bearing sand and pebbles in great quantities past them and over them and grinding them down as the rush goes on, till finally they are worn away and their particles are all carried off to the sea; it may take centuries, but it will be done.

The large blocks may especially attract our notice, but the smaller blocks and those stones that break off from the limestone beds everywhere and cover the surface over a large part of that formation, and the "gravel" of the older formation, are, on account of their great abundance, of much more importance. And in regard to them we notice that they must be continually shifted down the hillsides and farther and farther along the plains, every heavy rain that falls moving some of them, till they also are carried away to the sea.

The scattered blocks from the limestones are especially abundant on the steep slopes of the hills which form the northeastern edge of the Central Slope, but may be seen everywhere over the surface of the marl district. Sometimes they are corals, but more commonly are only blocks naturally formed by the jointing which we have seen both the limestone and the blue-beach layers to possess. Smaller fragments from the strata fill the soil. In the older formation the pieces broken out of the layers of rock and the finer material resulting from their decomposition under the action of the weather, make up together a coating of debris over the bottom rock which sometimes reaches a thickness of from twenty to thirty feet, and effectually conceals the rock below. Where this coating is shallow, as it commonly is on the slopes, the rills sometimes cut through it down to the original rock and cut up a portion of that rock to add to the gravelly covering. In the watercourses we can see how this covering is brought down by the streams and rearranged to be again carried farther on, till at last, though perhaps after the lapse of centuries, it must eventually reach the sea.

We have seen, then, that over the whole surface of the island the destructive forces, chemical and mechanical, are constantly at work; but in any case their action in lowering the general level of the country must be extremely slow.

Perhaps it is next to impossible here in St. Croix, where the streams are so short and so numerous, to come to any clear idea of the rate at which the island is being cut down and carried into the sea, but in larger countries, where the waste from extensive districts, or even great regions, is accumulated in one large river and by it carried into the sea, it is possible to make a rough computation of the amount of stuff carried yearly to the sea, and with the extent of the area known from which this stuff is brought, it is thus possible to say at what rate the area in question, on the average, over the whole surface, is being worn down. Professor Huxley tells us, for example, in his "Physiography," that the Thames carries yearly to the sea fourteen millions of cubic feet of solid matter, and that the effect of this immense work is to lower the land of the Thames basin by the eight-hundredth part of an inch in a year. In other words, it would take 800 years to lower the level of that tract of country by the average amount of one inch, and nearly ten thousand years to lower it a foot. Ten thousand years! And yet the difference in the landscape would not be perceptible, except, perhaps, in some particular spots!

The rainfall in St Croix is double that of the Thames valley, but in other

respects the destructive agencies are probably not greater, and if we allow the results here to be twice as great as what is known in the Thames valley we see that it would take 400 years to lower the surface of our island on the average by a single inch, and a similar statement, varying according to conditions, may, of course, be made in regard to other lands. No wonder then that we speak of the "*everlasting hills*" and regard everything as permanent. Yet it is certain that there have been enormous destructions of the land masses—hard masses, too,—in such a way that they have been ground down, not by a single foot, but by hundreds, or even thousands, of feet, so that we can only conceive that geological time must be reckoned rather by *millions* than by *thousands* of years. What an immense period we must allow, for example, for the cutting down of those enormous folds of the hard rocks of our older formation, which we have seen must have formerly existed, but which have been planed down to a small fraction of what they must once have been!

Such calculations as the above have, however, only a general value, for we have no means of judging of the rainfall of the past,* neither is it possible to state, except in a wide fashion, under what other conditions the destructive forces acted; we must, therefore, remain content with the general conclusion which the study of the strata and the study of the present conditions force upon us, namely, that vast periods of time must be allowed for the sculpturing of the surface of our island into the forms which now adorn it. And this looks no farther back than to the last elevation, when the mass of the "blue-beach" rocks was thrust up bearing the limestone beds on its surface. And here we are brought to a question which will considerably affect our conception of the work which has been done and the time which has been taken in this last great and still continuing process of the sculpturing of our island's surface. How far did those limestone strata then lifted up extend over that surface? Did they extend over the whole of it, so that we must regard the blue-beach rocks as only exposed to our view by the partial removal of the limestones? That may have, indeed, been so. It may be that the whole of the east end and north side of the island were covered with the limestone beds as well as the centre and south which are now so covered; but we have, of course, no right

* It should be remembered that the rainfall depends largely on the elevation of the land, and may vary greatly among islands situated in the same geographical region and even when they are near to each other. Porto Rico is not more than about 70 miles distant from Santa Cruz and very nearly in the same latitude; but it has elevations three times as high as ours, and in a large part of its mountain region the rainfall is more than double ours.

In connection with this subject it may be noted that the July number of the *Monthly Weather Review* for 1906 contains an instructive article from the pen of Mr. William H. Alexander of the Meteorological Station at San Juan, on the meteorology of Porto Rico, in which he gives a map showing the distribution of the annual average rainfall in the island. Only in one part, lying along the south coast of Ponce and its neighbourhood, is the rainfall so ~~much~~ low as in St. Croix, namely, under fifty inches (ours is about forty-seven inches); the fall is rather larger (fifty to seventy inches) in the extreme northwest, then towards the interior, seventy to ninety inches; still higher, ninety to one hundred and ten inches; and around El Yunque, the highest mountain (about 3,300 feet) the fall is over one hundred and ten inches. As a consequence of the great rainfall, streams which are considerable in the rainy season run to the coast, cutting out deep ravines and leaving sharp ridges between them. It follows that the work of levelling must go on in Porto Rico at a much faster rate than with us.

to assume that it has been the case. That the limestone formation has originally been much thicker and much wider spread than we now find it is certain; but farther than that general assertion it does not seem possible to go.

As already said, we must allow long ages for the recent sculpturing of the island before we get back to the time when the building up of the limestones was completed and they were pushed up above the water; but to these come those other vast ages while the limestones were being extracted from the sea-water by the several living agents and being built up slowly in the sea; farther back again, before those long ages of building, came the long ages of the earlier destruction, when the great folds of the clay formation were everywhere being cut down to expose the upturned edges, those edges which were to be lowered into the sea and to receive the limestones; lastly, we go still farther back and contemplate the long-continued building up in the sea, most likely from volcanic products, of the numberless strata that make up our clay or blue-beach formation. How vast a period must thus have elapsed from the deposition of the oldest visible layer of our island's rocks to the present time, when we see those rocks being destroyed once more to be added again to the materials accumulating in the bed of the ocean!

CHAPTER IX.

Connection of the foregoing with the Physical Geography of the Island.

From our study of the stages through which our island has passed it seems to be plain that its present form, both generally and in detail, must depend on three things: firstly, the quality of the materials of which it is composed, next the mode of its elevation, and thirdly, the mode of its sculpturing. The information which we have been able to obtain on these subjects will help us to form some conception of the way in which the existing physical features of the island have originated.

In considering the elevation which followed the deposition of the limestones, which we may call the *recent* elevation, as distinguished from the earlier elevation which followed the deposition of the blue-beach rocks, we see from the form of the island that the main movement has been from about north-by-west. In the Western Oblong the arrangement of the limestone strata, as well as the surface form, shows us that only *one* main wave of the earth's crust has been produced here, namely, that which has resulted in the forming of the northern chain of hills. When we pass to the Eastern Triangle we find a different condition. Here it appears necessary to assume that there have been two waves, the northern wave being shown in Buck Island and the neighbouring bank, the southern and more important wave in the East End range of hills. If layers of limestone now covered the flanks of this range as they cover the southern flank of the northern hills, we should probably see these layers sloping away on *each side* of the range, thus revealing the *second or southern wave form* which we assume to have been the cause of its formation.

The fact that the hills in the Eastern range are seen to form three divisions appears to be good evidence of two cross elevations, such as are found in the central and west parts of the island, as revealed there by the dips of the strata of the newer formation, and which would in all likelihood be similarly revealed in the east, if the limestone now existed there. The crosscut through the Christiansted Hills known as Spring Gut originated most likely in a split at the top of the arch formed by these hills as they rose from the sea, or possibly in a great north and south fault across the strata. It is a striking feature in the local geography, and, as already noted, the "saddle" which it forms is recognized as a well-known landmark for vessels arriving at the port of Christiansted.

The *Neck* shows a veritable break in the structure of the island, as may be seen by the deep water forming a bay opposite to it, as well as by the existence of the synclinal arrangement of the limestone rocks of the land. In the low hills which at the back of the Princess Plain border the Central Slope the dips are to southeast and southwest, so that there seems to be no evidence of these beds forming an arch going over to northeast, unless, indeed, such evidence is presented in the small Cay in Christiansted Harbour, which is entirely com-

posed of a conglomerate formed of well water-worn pebbles of the older formation embedded in calcareous mud, and showing apparently an irregular stratification dipping towards the north. The attention of the writer has been called to a bed of similar conglomerate which crops out on a grassy knoll to the east of the road as it goes over the top of Evening Hill, and which possibly may be a continuation of the deposit at the Cay. This conglomerate of the Cay, although so small a deposit, has in any case great interest, and especially so if further examination should show that it is not a recent deposit, to be reckoned as only a little earlier than our beach and reef limestones, but that it belongs to the great formation covering the centre and south of the island.*

It is, at all events, probable that the limestones of the Central Slope did bend over to the northeast, and that the arch which would have revealed this fact has been removed, perhaps in the first instance by the action of the sea on the arch as it rose above the water, and later by the rains and consequent rills which are still wearing back the hill front. Since the supporting blue-beach rocks must have shared in this arching, the comparatively low dip of these rocks in some parts of Christiansted may possibly be due to it; but on the other hand it should be noticed that rocks of the same kind at Judith's Fancy dip at about 45 degrees, so that fuller observation is needed before any clear evidence in this direction can be adduced.

In regard to the Central and Southwestern Plain, the interesting question arises, how far has it been formed by the sea and how far by surface drainage? That the sea passed through it at an early period in the course of the elevation seems to be likely; but the present form of its surface is certainly due to the streams which during rainy seasons course over it. The fact that sea-shells are found in various parts of it is no evidence, as some observers have supposed, that the sea has recently been there, those shells having undoubtedly been left by the Caribs on their visits to the forests or to their cultivated grounds. This explains the presence of all the bivalve shells and some of the univalves, while many of the univalves, found in nearly all parts of the island, have been carried inland by the hermit crabs, whose cast-off homes they are. That the present form of the plain is due to the streams which cross it we may see from the shallow depressions which those streams have formed and into which the water on either hand runs, bearing away the soil so as to leave slightly rounded surfaces between the watercourse and its next neighbours.

The above remarks as to the action of the streams apply to all, or, at all events, most of the plains in the island. The Parade Ground, east of Christiansted, though on only a small scale, furnishes an instructive example. If in a dry time we enter the watercourse on the west side of the small triangular

* From an inset chart of Christiansted Harbour on Captain Parsons' Chart of Santa Cruz it appears that "The Cay," called also Protestant Cay, is about 270 yards long from north to south and about 100 yards wide. Its highest point is 34 feet above sea-level. At its northern end are the ruins of an old fort (Fort Sophia Frederica). There are also residences for the Pilot and his staff, and a large cistern with collecting apron. In excavating for the cistern the same conglomerate was taken out as is seen on the surface.

plain we find its upright banks to exhibit sections showing the gravelly debris from the hills, and in some parts we find the watercourse widened, and we can see that new deposits of the same debris are being laid down on its widened bed. On the other (eastern) side of the Ground we find a similar, but abandoned, watercourse. It is nearly as deep as the western one, but big trees are now growing in it, showing that no heavy current has passed along it for many years. Possibly it may never be opened up again; at present it serves only to carry off the drainage from the adjacent hillslope and from part of the Ground, which we may notice has a very slight rise in the middle. In earlier ages it is not unlikely that the stream, which, as we have seen, now runs along the west side of the Ground and formerly also the east side, wandered from side to side, bringing down the debris and extending and levelling the little plain to the form in which we now find it.

The way in which a stream may lower the surface of a plain is well illustrated in a watercourse which crosses the plain west of the estate Longford. To the south of the highroad it will be seen that the stream is cutting into its east bank, which shows vertical walls of debris that frequently break away and fall into the watercourse in considerable masses, while on the west side there are no such walls, and only at a considerable distance from the stream is there even a sloping bank to indicate where the water has once been.

In connection with the plains we may consider the case of the lagoons and seaside ponds. Krause Lagoon, on the south side of the island, is a rather extensive area of islets and mudbanks, separated by water channels and ponds connected with each other, and on its western side with the sea. The islets and mudbanks are grown over with the red mangrove (*Rhizophora Mangle*) and the water is always more or less muddy. Along the seaward side of the area we find a bank of sea sand of the ordinary character, but along the land edge we find everywhere that the shore and the bottom are covered by clay and fine gravel, which have been carried into the lagoon from the land. It follows that the lagoon is being slowly but surely filled up by drainage from the land. It will, at some future and distant age, become a plain. The streams, which now rush in from time to time, spread out over it and drop their mud all over its bottom; but the streams of that future day will continue their courses over it, partially cutting into it and bringing the heavier debris to lie upon it, and thus a plain of the ordinary type of the coast plains of our island will be created.

The two ponds of *Southgate* and *Great Pond* are, in a similar manner, being filled up. Their existence seems to imply that after the plains, of which they occupy the lowest part, had been formed by the streams from the hills, there was a sinking of the land, producing bays of the sea, that the sea, in the way described in an earlier chapter, then formed tongues of sand shutting in the innermost parts of the bays and thus forming salt ponds or lagoons, which have since been gradually filling up. The sand bar in each case is broken through after heavy rains, when the accumulated water in the pond forces an

exit, but otherwise the bar remains permanent, and is covered with a strip of the usual seaside vegetation. There is a similar, but much smaller, pond at the estate *Coakley Bay*.

The lagoon at Christiansted and the creek known as Salt River differ from the ponds above mentioned in being deeper, the former having a depth of eight or nine feet, the latter over twelve feet in the deepest parts; but they, like the other enclosed waters, are slowly filling up. The Christiansted Lagoon has two branches, each of which ends in flat, swampy land; and when we examine these places we can see that it only requires time to extend this condition through both arms and finally through the body of the lagoon. Salt River, in its innermost portions, shows the same tendency, and at its upper end are some fine, flat, fertile lands that have doubtlessly resulted from a like filling up in earlier times.

This "filling up" of several areas around the coast seems necessarily to imply a previous sinking of the land sufficient to form the ponds and lagoons now being slowly filled. That such sinking has taken place appears to be confirmed by the form of the bottom of Christiansted harbour, the deepest part of which, passing through the Long Reef by the Ship Channel, seems only to be a continuation of the watercourse coming down from the great rift in the hills known as "Spring Gut." The channel is *kept open*, it is true, by quite a different agency, namely, the outward current resulting from the accumulation inside the harbour of the water dashing over the Long Reef; but its origin is probably as suggested.

A sinking, such as has been above supposed to have taken place, need not, however, have been the last movement of the island's surface. The position of the beach limestone, on which part of the town of Frederiksted stands, seems indeed to imply a slight recent movement of elevation, if not general, at all events in that part of the island.

When from a point of vantage we look down the course of one of the larger valleys, such as that which passes through the North West Hills from Mt. Stewart and opens out on the plain near Prosperity, we are struck not only by the beauty of the landscape, but by its complications, and we get the same impression when we turn to the map and see how the stream is here and there turned aside, and how the spurs from the side hills come out into the valley, leaving even at times what seem to be almost isolated hills. Yet there can be no doubt that when the valley first began to be formed the case was simple enough, the drainage merely followed the slope that had been given to the mass by the elevating forces, whether the slope was given by a force acting in one direction or whether it was the resultant of two or more forces acting in different directions. Hence when we have geological evidence of the direction of the recent force we generally find the geographical evidence to coincide with it—that is to say, the streams run in the direction of the dip of the strata. If they do not, there must be special grounds for the divergence, though perhaps we may not be able to discover them. In general we have seen that this

agreement in these two classes of evidence exists in St. Croix ; but there seems to be some divergence on the western edge of the Central Slope, where the valleys, even on the extreme edge, as we now have it, do not tend inwards as much as we should expect ; while on the other hand the dip of the rocks turns in more than we should expect from the direction of the synclinal axis. Does not this suggest that the anticlinal axis of the Mt. Eagle Ridge has been lifted considerably at a comparatively late period—that is to say, after the valleys in question had been formed, or partially formed, and that this lifting has thrown the dip of the strata more inwards? This is, of course, only a speculation, and is here mentioned merely as a possibility that may be worth attention.

The observer who becomes interested will find everywhere among the physical features of the island matter for inquiry, and after a time will see in the hills, the valleys and the plains old friends about whom he already knows something and concerning whom he is always eager to learn more.

CHAPTER X.

Relation of the Structure of St. Croix to that of the other West Indian Islands.

A glance at a map of the West Indies shows that the islands are arranged along two great lines or axes, one lying east and west, the other lying north and south; the former shutting in the Caribbean Sea on the north, the latter shutting it in on the east.

The great east and west axis, about 1,200 miles in length, divides in the island of Hayti, in a westerly direction, into two branches, one passing along the northern peninsula of the island and through Cuba, the other passing along the southern peninsula and through Jamaica. From Hayti the undivided axis passes eastward through Porto Rico and ends in a group of small islands, of which St. Croix is one. St. Croix belongs, then, to the east and west axis of the West Indies.

The north and south axis, about 500 miles in length, consists of a curve of volcanic islands, the curve being convex to the open Atlantic. The islands rise rather abruptly from the Caribbean Sea, but have on their eastern side towards the north two wide banks from which rise several non-volcanic islands.

The obvious points of contrast between these two axes are, that one has for the most part large islands along it, with hardly any volcanos, while the other has in its main line only small islands, all of which have one or more volcanos, mostly extinct, it is true, but some of them, as recent experience has proved, still capable of tremendous occasional activity.

Our examination of the structure of our island revealed two great periods of elevation, one since the deposition of the limestone formation, and another, an earlier period, following the deposition of the blue-beach rocks. In both cases the position of the layers showed that the principal pressure came from the north; in the earlier movement it was from north-northeast, and in the later movement it was from north-by-west. We may be sure that there were definite causes, not only for the movements both being from the north, but also for the difference of three points in the direction of the two movements, though we may not be able to discover what the causes were.

In this connection it is interesting to note that east of Porto Rico the island of Vieques (or Crab Island), nearly as long as St. Croix, lies almost parallel to it, and has, therefore, probably been lifted on the crest of a wave, pushed up by the same movement as that which has lifted our island. Whether there is any geological evidence in Vieques for this theory, the present writer is unable to say. Professor Cleve, after saying that he was in the island only for a few days and under very unfavourable circumstances, so that he knows very little about its geology, remarks as follows: "Near the shore of Puerto Mula an altered dark green rock is visible, but at a short distance from the coast occurs syenite-like diorite, which seems to be the most important rock of the island, producing by alteration a very fertile soil. The diorite has the

same appearance as the rock of Virgin Gorda, and has, also, a spheroidal structure. In the eastern part of the island some stratified white rocks seem to occur, but having seen them only from the sea, at a considerable distance, I cannot give any description of them." From our present standpoint it would be very interesting to know something about those "stratified white rocks."

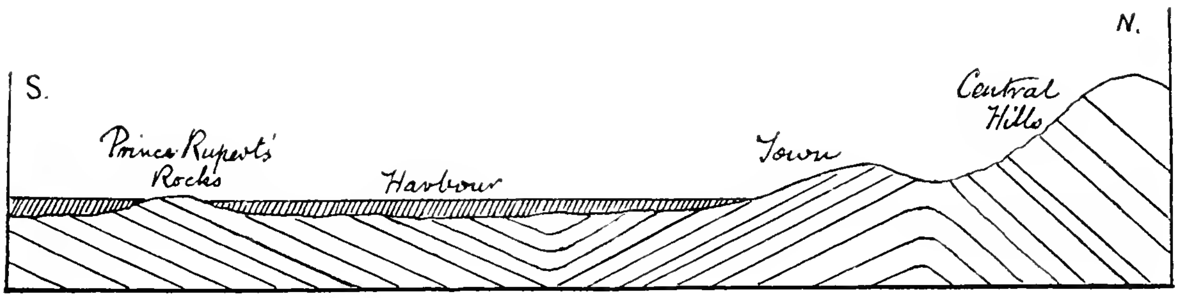
Turning to our sister island of St. Thomas, 40 miles away from us to the north, we find no "stratified white rocks" there to help us. St. Thomas has the older set of our Santa Cruz rocks, but the younger set (the limestones) are entirely wanting. Possibly they were lodged there on the top of the older rocks, but have been since washed away, as perhaps they were, from the tops of the northern and eastern hills of St. Croix. However that may be, it is certain that the limestone system of St. Croix is entirely wanting in St. Thomas, and consequently we lose the *geological* evidence as to the direction of the *later upheaving force*. About the direction of the more *ancient upheaval* we have, however, very good evidence, and it is extremely interesting to find that the ancient rocks have been thrust up in ridges or waves, lying parallel to the like waves in St. Croix; in other words, the St. Thomas rocks have been subjected to the same thrusts as have acted on the similar ancient rocks of St. Croix. For evidence of this we have the quarries and other rock exposures in and about the town. In a quarry on the west side of the "Field" we find plainly stratified rocks of the indurated clay type, much like those we see near Christiansted, and we find that they dip at a high angle (about 40 degrees) to about northeast. Across the "Field," on its eastern side, we find another quarry showing hard blue-beach conglomerate. Most of the embedded fragments are somewhat rounded, as though water-worn, and the mass is so thick that we at first discover no stratification, but after a careful search, we find in the northwest corner of the quarry some fine-grained blue-beach without embedded pebbles, and showing ribbon-like markings indicating stratification, the layers dipping in the same direction as those of the first-named quarry. When we ascend the hill towards Louisenhoi and Ma Folie, we see similar indications of the original stratification of the rocks and of the dip being to about northeast. But when, starting from our first named quarry, we move southwards towards the town, we soon meet (near the Epidemic Hospital) with similar indurated clay rocks distinctly stratified, but dipping, not to northeast, but to *south* or *south-by-east*. If we ascend the road up the hill to the west we shall find further evidence of this southerly dip, and we shall meet with it here and there in various parts of the town. Hence we have discovered that the town stands on the south slope of a wave of the old rocks, which, immediately behind it towards the north, has been cut down into a slight depression, while the northern slope of the wave appears just beyond and in the higher hillsides.

This wave in the strata is of especial interest, because it appears, in the hardness of one of its beds, to be the cause of the peculiar hill spurs which have given the opportunity of building a considerable part of the town on

three small hills, thus giving rise to the picturesque appearance so greatly admired by visitors to the island. Many residents must have noticed the great blocks of rock that lie about the uppermost parts and back slopes of the middle and eastern hills, as well as the fourth hill, still farther east, on which "Blue Beard's Castle" stands. It is obvious that these blocks are from the broken edges of a thick and hard stratum coming up at a moderate angle from the south. The somewhat softer rocks below this bed have been cut away where they crop out beyond it towards the north, so that a slight hollow has been made there in each case, most marked behind the easternmost hill, where it is occupied by the street known as "Polyberg."

If we add to the above observations one from Professor Cleve's account of St. Thomas, we are introduced to a repetition of the northern of the two above named dips. The Professor writes of the blue-beach rock: "In the harbour near the fort and on the small cay of *Prince Rupert* the rock forms regular strata of half a meter (nearly 20 inches) in thickness. Their strike is S.S.E.—N.N.W. and dip 30 degrees to E.N.E." Putting this observation with those described above, we may illustrate the probable positions of the strata in a rough way by the accompanying diagram (Fig. 27), in regard to

FIG. 27.



which it will, of course, be understood that only the position of the anticlinal axis to the back of the town can be given with any approach to accuracy; the synclinal axis must come somewhere between the town and Prince Rupert rocks, but cannot be more closely indicated, at all events not without fuller investigation.

It seems then pretty clear that the ancient elevation of the rocky masses in St. Thomas has been brought about by the same force as has raised the ridges of the older rocks in St. Croix, and the possibility at once presents itself that the force is the same as has at first pushed up the whole great east and west axis.

There was, no doubt, a recent lifting of St. Thomas at the same time as the corresponding lifting of St. Croix, that is to say, after the deposition of the limestones; but as St. Thomas lacks these limestones, we can only judge of the direction of the force from the form of the island, and the line of its length would seem to justify the belief that the recent force of elevation has

acted in the same direction as in the ancient elevation, that is to say, from about north-northeast, and not, as in St. Croix (? and in Vieques), from north-by-west.

The existence of an unusually deep sea channel between the two islands need not present any difficulty in supposing the action, on both sides of the channel, of the same pressure through the earth's crust. When we find, on the chart, depths of 1100, 1500 and even 2500 fathoms, we may at first think of these depths as indicating a great chasm in the earth's crust, so great that it would cut off the possibility of any pressure being exerted across it; but when we compare these depths with the width of the channel (40 miles) we see that there is not such a great depression after all, and the difficulty disappears. (See Fig. 28.) Besides which, we must remember that the deep channel may not have existed when the early upward movements took place. Indeed it is probable that this remarkable channel is of quite recent origin.

Fig. 28.

The foregoing observations are sufficient to show the connection between the structures of the two islands. There are, however, some differences. Professor Cleve describes the distribution of the rocks of St. Thomas as in three bands, the most southerly, as shown along the coast and in the islets as far west as Little Saba, he describes as felsite (with blue-beach subordinate). The felsite is a very hard rock, usually of a creamy white colour with much red in it. The south side of Little Saba, as seen from the sea, presents a striking exhibition of this rock. The Professor remarks in regard to that islet, that it is commonly supposed to have been a volcano, which, he says, is not correct, "The rock being of the same kind as at Red Point, a fine-grained felsite, sometimes altered to kaolin." There is very little felsite of this kind in St. Croix. The strip beyond this felsite strip, to the north, is described by Professor Cleve as "blue-beach with felsite subordinate." It is this strip to which the rocks of the town and the central hills already considered belong. Lastly he mentions a band of "stratified metamorphic rock (clay-slate, etc.)" stretching along the north coast from Northside Bay to Coki Point in the east, a strip which may be compared with the clay-slate of St. Croix. The Professor remarks under the head "Blue-beach" (page 40): "It is very likely that the clay-slate of the Virgin Islands is only an exceedingly fine-grained variety of blue-beach."

The islands of St. John and Tortola, to the east of St. Thomas, much resemble the last named in their rock structure, only that the strike of the strata lies east and west. Virgin Gorda differs mainly in exhibiting a large area of unstratified diorite, which is often mistaken by visitors for granite.

Anegada, which ends the chain, is, however, quite different from the other Virgin Islands, being a flat island entirely composed of limestone of quite recent date, as shown by the fact that it contains only shells of species which still live in these waters The Bahamas, which are commonly regarded as a continuation of the Caribbean axis, are of similar structure.

Before turning west to the large islands, it will be interesting to notice that, judging from Professor Cleve's observations in Anguilla, St. Martin's and St. Bartholomew, those islands belong, not as we might have expected, to the great volcanic axis, but to our own east and west axis. He says, namely, that the dips of the rocks in St. Martin's and St. Bartholomew are to the south; and about Anguilla he reports that in the abrupt cliffs of the northern coast the rocks on which the limestones of the island rest may be seen; it is a kind of trap. From these observations it would appear likely that there has been a continuation of the great axis eastward and that this has been connected with the pressures which have raised those three islands.

When, however, we leave the bank on which the above islands stand, and arrive, going southward, at Antigua, the case is quite different.*

In Antigua the tilt of the strata is from the southwest and they dip away to the northeast. Antigua is, therefore, geologically a dependency of the north and south axis. The island shows three sets of rocks, two of them of ultimate volcanic origin, the other consisting of limestones and marls originating in the ocean. As in St. Croix, the older rocks have in a past age sunk into the sea and have had the limestones deposited upon them. There are, however, considerable differences. The older formations do not appear to have been raised into ridges as in St. Croix, and the limestones have, therefore, not been laid down on the edges of the older formation, but on the surface of their uppermost beds. Another great difference is that the upper part of the older rocks (the second of the two groups) is all clearly stratified, consisting of regular beds, mostly of hardened clays and sandstones, and has not undergone any marked alteration as a mass. On the other hand, some of the beds have been silicified in a remarkable degree. The conversion into silica has taken place in some of the marine limestones interstratified with the clays, in which we may find corals and shells partially or entirely converted into flint; it has also

* Reference to a chart of the West Indies shows that Antigua and Barbuda, its dependency to the north, both stand on a bank lying north and south. Barbuda is a flat island, having an elevation along the east shore known locally as the Highlands, the highest point of which is given in the chart as 115 feet. The rocks in that part probably belong to the same formation as the limestone rocks in the north of Antigua, all the rest of the island is made up entirely of a recent limestone, full of shells of the same species as now live in the adjacent waters, and to be compared with the recent limestone of Frederiksted. The writer has seen there the ruins of an old castle, all the stones of which had been cut from the limestone of the flat, and were full of small shells which could be matched from the shore of the neighbouring lagoon.

happened in beds laid down in fresh water ponds, where fresh water shells along with the beds themselves have been similarly converted; and associated with them a great quantity of fragments of various species of wood have been so perfectly preserved in the form of agate that the minutest details of their structure are beautifully exhibited.

The amount of silica in solution during the deposition both of the stratified clays and the later limestones, must have been enormous, for besides the silicified beds and fossils, both marine and fresh water, already mentioned as lying among the clay beds, the present writer has seen in the limestones of the Northwest true flints resembling those found in the chalk, and has seen on the north side of the islet known as Long Island a beach of rolled flint pebbles, very much like such beaches on the south coast of England.

It appears, then, that while the islands of Anguilla, St. Martin's and St. Bartholomew are possibly to be regarded as geologically belonging to the same axis as our own island, Antigua and the more southerly non-volcanic islands, including Barbados, are related to the other great axis, namely, that of the volcanic chain.

When we now turn westward and follow the chain of the larger islands, we find that all of them, from Porto Rico to Cuba and to Jamaica, have extensive limestone formations on their seaward slopes and even high up in the mountains, while the central and highest parts are formed of rocks somewhat similar, and in some cases very similar, to the older rocks of our own island. These older rocks in the several islands have also been commonly pushed up at high angles, are much altered and contorted, and are penetrated by igneous rocks just as the older rocks of St. Croix. From all which it may be concluded that the principal events in the geological history of St. Croix have been common to the whole line of the larger islands. They too have been pushed up, have been denuded, have sunk again and have received the limestone beds on the worn edges of their strata, and then have once more been forced up above the level of the sea.

Hence we see that the east and west axis of the West Indies is a great mountain chain, which has probably been raised as a whole by the same forces acting through its whole length. We can already see, however, in the different heights of the various parts, evidence that the conditions have not been alike in all of them; and a detailed study of the islands would no doubt reveal many important differences.

Investigations concerning the distribution of the plants and land shells of the West Indies have shown the great probability of the islands and the banks from which they rise having at one time been continuous land, and having since sunk so as to allow the water to flow over some of the cross valleys and thus to break up continuous chains of mountains into chains of islands. The depths in many of the channels between the islands exceed a thousand fathoms or six thousand feet. When, however, we recall what we have learned from the study of the St. Croix rocks, about cross elevations and depressions, it

seems not impossible that the present considerable depths of water in some of the channels may be the result of local depressions, so that, although it would take a general rise equal at least to the above-named depth to bring the bottoms of the present channels above the sea level, it does not follow that the sinking of the land in its entirety by that amount has been necessary to cause the existing separation.

Some sinking appears, however, highly probable, and we have already found, while discussing in the last chapter the ponds and lagoons of the island, that these present some local evidence for such a movement, which, however, would probably be the last stage only of the larger movement supposed to be revealed by the present distribution of the plants and land shells.

So far we have seen that the geological history of St. Croix appears to be bound up with the history of the formation of the east and west axis of the West Indies, but there still remains the question: In what relation does this axis stand to the great north and south axis? As the answer to this question involves some wider considerations than any yet taken up in these pages, it is best to leave it over for the next chapter.

CHAPTER XI.

The Relation of the Geology of St. Croix to Geology in General.

The reader who may wish to extend his studies to the construction and history of the earth's crust as shown in other parts of the world will find valuable help in such works as Huxley's Physiography and Marr's Introduction to Geology, or, if desirous of following up the subject more fully, then in Lyell's Principles of Geology and Dana's Manual, but for the sake of others who may wish only a brief statement of how our local geology stands to geology in general the present chapter is added.

The subject appears to fall naturally into three parts; for we may compare the rocks of St. Croix to those of the world in general—firstly, in regard to their *modes* of origin; next, in regard to the *times* of their origin relatively considered, or in other words, their relative ages; and lastly, we may compare them in regard to their subsequent history.

1.—Origin of the Rocks.

In our examination of the St. Croix rocks we found that nearly all of them had been laid down in the sea, and must therefore be classed as *aqueous* or sedimentary rocks, but that there were a few which had evidenly been forced up from below in a molten state, and must therefore be classed as *igneous* rocks. Both these great classes of rocks are found in all parts of the world, some of them much like those of our own island, but others very different from them.

Igneous Rocks.

Most geologists have agreed to arrange the igneous rocks in two great classes, namely, the *Plutonic* and the *Volcanic*.

None of the *Plutonic* rocks appear ever to have been thrown out by volcanoes, but they seem to have been formed deep down in the earth's crust, hence their name, from Pluto, the god of the lower regions. The chief members of this class are the various kinds of granite. The composition of granite varies somewhat, but commonly it consists of the minerals felspar, quartz and mica in distinct crystals. It is a very important rock, and was formerly supposed to be the oldest of rocks and to form the base rock of the earth's crust, and, although this view has since been modified by the discovery of granite among the later formations, there can be no doubt that it is very widely distributed and that it has afforded by its decomposition a considerable part of the materials of the stratified rocks. Some granite is extremely hard and slow to change, but there are other kinds which decompose rather easily; the felspar decomposes to a clay, the finest being known as *Kaolin*, the clay from which fine porcelain is made. When rills pass over the decomposed granite they wash away the clay and redeposit some of it in beds, carrying the rest ulti-

mately to the sea; the quartz crystals are separated from the mass and may be redeposited, and if they reach the sea they are rolled on the beach till their edges are removed, and they may then come to form beds of quartz sand on the sea bottom.

Granite is exposed in great and widely extended masses in many parts of the world and is sometimes found to have been thrust in between layers of stratified rocks, or to have been forced through them as dykes and veins. The present writer has not seen granite in any form in the St. Croix formations, but Professor Cleve mentions granite veins as occurring in several of the islets around St. Thomas and in Tortola.

Another important rock, which also contributes largely to the supply of material for the stratified rocks, is gneiss. It consists of the same kinds of crystals as those which make up granite, but the crystals are more or less arranged in layers, sometimes with barely a tendency to that form of arrangement, so as hardly to be distinguishable from granite. Where, on the other hand, this arrangement is strongly marked it suggests that the rock has first been stratified and afterwards altered by heat. Many geologists, however, are of the opinion that at least some kinds of gneiss, and possibly all kinds, are true igneous rocks that have rearranged their constituents under the action of heat and pressure; that they are, in fact, altered igneous rocks.

The Volcanic Rocks.—Dr. J. W. Spencer, writing about the recent earthquake in Jamaica, in the magazine "Science," for June 21, 1907, after pointing out that the earthquake could hardly have been due to volcanic action, since Jamaica is far removed both from the West Indian and the Central American volcanic chains, adds: "Moreover, Jamaica is not volcanic, with only one Pliocene volcano upon the northern coast." If there is one extinct volcano in Jamaica it is possible that others may be found in Cuba and Hayti when those islands come to be more thoroughly examined. However that may be, the east and west axis presents a great contrast to that which lies north and south, for, while the former has one volcano and possibly a few more, the latter is full of them. Most of these show no signs of activity and may be regarded as extinct; others are evidently only slumbering, and in the case of Mont Pelée in Martinique and the volcano of St. Vincent the eruptions of 1902 proved how disastrous their occasional outbursts can be.

Many of the West Indian volcanoes, perhaps nearly all, have distinct craters, but this does not commonly appear in a distant view. One of these, however, namely, that of the island of St. Eustatius, is a typical volcano. A sight of it is very instructive, for not only do we get a hint of the way in which the material far down in the earth's crust may be brought up and piled on the surface, but in the numerous ravines that score its slopes we see how the rains may eat into and remove this material and finally level the great pile which the volcanic force has built up The St. Eustatius volcano is about 2,000 ft. high. From some points of view, both on the island itself and on the neighbouring sea, the crater can plainly be seen to form a hollow, and the volcano is locally

known by the expressive name of "The Quill." The diagram (Fig. 29) shows an outline of it as seen from the north.

Fig. 29.

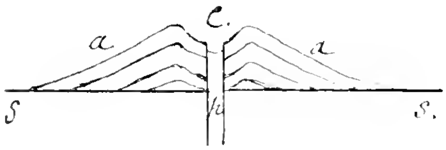


Fig. 30.

In some cases the conditions during a volcanic eruption are such as to permit of a spectator remaining on, or even within, the edge of a crater during the eruption. In this respect Stromboli, in the Lipari Islands, which has recently (May, 1907,) astonished the world by its activity, has hitherto presented a specially favorable field of study, because, although nearly always active, its activity has usually been of so moderate a character that the explosions which take place at short intervals at the bottom of the crater could be watched with very little danger to the onlooker. In this way it has been found that when an explosion is about to take place, there rises on the surface of the molten rock at the bottom of the crater a large bubble, which explodes, emitting a cloud of steam and of dust formed by some of the matter being blown into minute fragments. The explosion reveals the glowing molten mass below, and this lights up the column of steam and dust that has been thrown out from the vent, and thus gives rise to the popular but mistaken notion that flames issue from the crater. The dust produced by the explosion is known as volcanic ash, a name to which there can be no objection so long as we remember that there has been no combustion of any solid substance and that therefore the volcanic dust cannot be ash in the usual sense of the term. Where does the steam which causes the explosions come from? Formerly it was supposed to be from the surface water of the earth, which was thought to have reached the hot rock through cracks, but it is now generally believed that it comes from the rocks themselves. Chemical analysis shows that they contain a considerable portion of water, not as a separate substance, but in combination with other components of the rocks. The intense heat

releases this water, which comes away as steam as soon as the pressure on the overlying mass is sufficiently reduced by the approach of the highly heated matter towards the surface. The same may be said of the carbonic acid gas which is often found to come away from the craters and occasionally the sides of volcanoes.

There is good reason to suppose that the more important eruptions, even the mightiest, are caused in a similar way to the smaller and more frequent explosions in the crater of Stromboli. When a volcano remains quiet for some time, the molten rock in the upper part of the vent cools down and becomes solid; but when the mass below melts again the same pressure as before is set up, and as the melting process proceeds upwards the weight of the overlying rock at last becomes too small to prevent the explosion, which then takes place, shattering the plug at the top of the vent to fragments and throwing these high into the air, sending up at the same time a portion of the molten rock, blown into fine particles. The rush of steam and gas from the vent is often powerful enough to carry the finer particles several miles high, so high that in the West Indies they reach the region of the return trade-wind, where they then drift eastwards with the current, and may travel, as in the case of the several recorded eruptions of the St. Vincent volcano, several hundreds of miles in that direction, the St. Vincent ash falling not only on the island of Barbados, but on the decks of ships far out on the Atlantic. If they are not thrown to so great an altitude as that named above, they may yet be shot so high up in the trade-wind current that they are carried along by it for hundreds of miles, as was the case during the Mont Pelée eruptions in 1902, when ash from the mountain was brought down by showers of rain in St. Croix and St. Thomas, Martinique being distant more than 300 miles to the southeast, and even in Jamaica, more than a thousand miles from the scene of the explosions.

The heavier ash and the stones of various sizes are, of course, not carried so far, but fall around the vent. It is in this way that the cone and the crater are formed. The theory of their formation is indicated in Fig. 30, where we must let the few lines showing how the cone is built up, stand for thousands of thin layers of stones and ashes. The successive showers of stones and ash deposit most of their material not far from the vent, some of it slides down again inwards as well as outwards and in this way the cup-like depression as well as the cone is formed.

It sometimes happens in volcanic outbursts that the molten rock wells up into the crater, breaks part of it down, and then moves slowly down the mountain side. The flow constitutes a stream of lava, a true volcanic rock. Such a stream is generally full of small holes, caused by steam and gas; but is denser towards the middle than on the surface. Such flows of lava sometimes occur within the mountain instead of down its sides, the molten rock spreading itself in sheets between the beds of ash; sometimes the pressure within causes upright cracks around the vent, and into these the molten matter is forced

from below, giving rise to dykes. It may be asked how such facts as these last mentioned can be known? They are learned from old craters and from the valleys which are sometimes cut out by streams in volcanic districts and reveal the structure of the mountain slopes; particularly has this been the case with the ancient and long extinct volcanoes of Auvergne in Central France, where, although the cones and craters have been preserved, the mountain sides have been scored by streams, whose eroding action has opened up to the student of volcanoes many of the secrets of those wonderful natural agents.

As already remarked, there are no evidences of the existence of volcanoes in St. Croix; if there have been any they have been long since swept away, yet, as we have seen, there are abundant evidences of the action of heat, by which most of the older sedimentary rocks have been greatly altered and by which dykes and masses of igneous rock have been thrust in among the stratified rocks.

These igneous rocks of St. Croix, not being plainly of volcanic origin, would be placed by some geologists in a third class, intermediate between the Plutonic and the Volcanic, but as very similar rocks can be shown in some parts of the world to have been formed below volcanoes, it seems hardly necessary, so far as the rocks themselves are concerned, to make the distinction. If it is made, the igneous rocks of St. Croix may be described as trap rocks, and the question of their possible connection, or the connection of some of them, with ancient volcanoes, may be left open.

Geologists have found that volcanoes have existed from very far back in the history of the earth's crust. Those of the West Indian north and south axis appear, however, to have originated in a quite recent geological age, the ground for which conclusion will be mentioned later.

The origin of the heat which causes volcanic activity, as well as such alterations and such intrusions of trap as we find in St. Croix, has been much discussed. Some have supposed that the earth's crust rests on a globe of molten rock, which here and there oozes upwards and sometimes comes out on the surface; but it has been shown that this is impossible, since a crust so situated would be racked to pieces by tidal movements in the fiery ocean below. Others have supposed that, although the earth has so far cooled down that there is no such central ocean of fire, there are local patches of molten rock, from which the supply in the volcanic vents is derived. This view is still held by some geologists, while others maintain that the heat is developed by chemical changes in the rocks and by alterations of pressure as the earth's crust contracts, differences of opinion which show us that while the effects are known the causes are still obscure.

The Sedimentary Rocks

Having seen the relation in which the few igneous rocks of our island stand to the class generally, we may now consider the relation as it concerns the origin of the sedimentary rocks. It will be recalled that these rocks in St.

Croix belong to two very different sets, the younger set being of organic origin, that is to say, derived from living creatures which had extracted the lime of the hard parts of their structure from the sea-water; the older set being of *mechanical* origin, the material of its beds having been washed down from the land into the sea. Both these two great classes of sedimentary rocks, the organic and the inorganic, have their representatives all the world over. Let us first compare some of these with our own and afterwards see whether there are not other great groups of sedimentary rocks, which are not at all represented in St. Croix.

The Lime Rocks.

Varieties belonging to this class are common all over the world. One of the best known is chalk, frequently, though not always, a soft rock. It is mostly composed of minute shells and fragments of these, and many of its beds contain layers of the siliceous concretions known as flints. Flints, however, are not restricted to the chalk, for, as already mentioned, they are to be found in some of the limestone beds in the island of Antigua, though there do not appear to be any in those of St. Croix.

All limestones are probably of organic origin, though this cannot be said to be quite certain. Many that show no fossils when cursorily examined, are found on further examination to contain them, while some limestones are full of them; for example, the encrinite beds of the English carboniferous limestone, beds which are crowded with the stems of feather-stars, something like those which are occasionally brought up by our fishermen from the deepest parts of the banks, or again the Purbeck limestone, which has originated in fresh water and is full of the shells of fresh-water snails. Both these limestones are compact enough to take a polish, are consequently often used for ornamental purposes, and are sometimes spoken of as marbles. That name, however, ought properly to be applied only to those limestones which have been so much altered by heat and pressure that their origin is completely obscured; such are, for example, the marbles of Greece and Italy. As already mentioned, there do not appear to be any of these marbles or *crystalline limestones* in St. Croix, although some are found in the neighbouring Virgin Islands. In some parts of the world considerable beds of limestone are found in which magnesia in considerable quantities, occasionally equal to nearly half of the rock, is found. Such limestone is known as dolomite or magnesian limestone, and is supposed to have been formed in inland seas by deposition, as the result, in part at all events, of evaporation. It may, therefore, be classed as partly a chemical deposit. The last limestone that need be mentioned here is Oolite, or "roe-stone," a limestone made up of tiny balls of carbonate of lime all bound together as a firm rock, which, when broken through, presents a surface resembling the roe of a fish.

Clay Rocks.

The indurated clays and slates of our island may in regard to their origin

all be classed as mud-stones, and they have their representatives all over the world.

There are a few other important rocks which are not comparable with anything found in our island. The principal of these is the carbon group, including coal of various kinds, beds of mineral pitch, and graphite or black-lead, which has been formed from coal by heat and pressure combined. The carbon group has been produced from the vegetation of past ages, the plants having obtained their carbon from the air and their mineral constituents from the soil, and has, therefore, an organic origin. This is not the case with two other remarkable rocks, salt and gypsum, both of which have originated as the result of the evaporation of water containing these substances in solution, and must, therefore, be classed as chemical deposits.

Enclosed or nearly enclosed seas that are surrounded by hot and rainless countries naturally tend to become salter by excess of evaporation; while the water of the Baltic contains one and one-half per cent. of salt, and that of the Atlantic three per cent., the Mediterranean contains five per cent. and the Red Sea six per cent. If the channel which now connects the Red Sea with the Indian Ocean should ever be closed by the elevation of the surrounding land and the Suez Isthmus be raised, the Red Sea would decrease in area and increase in saltness until at last a great bed of salt would be deposited. The same thing might happen with inland lakes in a country where the climate was changing towards desert conditions. Beds of rock-salt are found in many countries (the nearest to us in St. Croix being Santo Domingo), and it cannot be doubted that they were formed in some such way as above suggested.

Gypsum, which is a combination of lime and sulphuric acid, is likewise a deposit from evaporation of inland water areas. It is often found in layers near the beds of rock-salt; the gypsum beds in the neghbourhood of Paris, from which the well-known plaster of paris is made, contain, however, freshwater shells, showing that the rock has been deposited in lakes, the water of which was fresh when the molluscs lived in them.

There is another important set of rocks that has no true representative here in St. Croix, namely, the sandstones. The sand from which these were formed is entirely unlike the sand of our West Indian seas. As we learned, in the beginning of our observations, our sand is of organic origin, being composed of the remains of marine animals and plants, but the sand of the seashore in many countries is a purely mechanical product, being originally obtained, it would appear, from granite and similar rocks in the way described under the remarks about granite in this chapter. The sandstones form immense beds in Europe, North America and elsewhere, and are of such importance in some parts that they have given names to two of the English geological systems, in which they are abundant. The doubtfully stratified *gneisses* and the various schists, which will be again referred to in the third section of this chapter, must also be included in rocks not represented in St. Croix.

We may now leave the question of origin and consider

2.—The Relative Ages of the Rocks.

While it is not possible to state the age of any geological formation in definite time measures of any kind, it is possible to ascertain the order in which the deposits have followed each other and thus to state their *relative* ages. In our own island we can see that the limestones and marls must be younger than the indurated clays, because they lie upon the clays; and we can probably extend this conclusion to apply throughout the east and west axis of the West Indies; but how are we to get beyond that? In order to see how geologists have been able to compare the ages of rocks in different countries or different parts of the same country, it is necessary to consider a few facts about fossils.

Fossils.

Fossils are the remains of living beings, whether animal or vegetable, which have been preserved in the rocks. Generally it is the hard parts, such as shell and corals, and the bones of animals, that have been preserved; but occasionally the forms of the softer parts have been preserved likewise, the forms of fishes, for example; and insects, with forms and colours perfect, have been kept for long ages embedded in tree gums, such as amber. The study of the ancient life revealed by fossils is known as Palæontology (meaning the study of ancient beings), and it is one of vast extent. It shows us that, going back in the history of the globe as recorded in the strata of its crust, we come to a time when hardly any of the species of plants and animals now living on the earth had any existence, but the period had a life of its own; beyond that again we come to another period, which, while containing some of the same fossils as are found in the later period, is also marked by a special set of its own; and so on. But it may be asked how did the palæontologists know that they were going back in time? Suppose we ask a similar question about our own island; how do we know that we are *going back* in time when we pass from the limestone formation to the clay formation? Simply because we find the clay formation *below* the limestones. The same reasoning applies to the more extended study. Now it happens that England has afforded a particularly good field for the investigation, for in that country the strata, though by no means free from disturbances, yet lie over each other in a regular manner, the lowest (oldest) being in the west and the others lying over them in succession till we arrive at the highest (youngest) in the east. This succession has been thoroughly studied by the English geologists, who have arranged the rocks in systems, some of which have been named from the most characteristic of the strata included in them, others from the parts of the world where they are conspicuous, and others again (The Tertiary division) from the relative abundance of their fossil remains belonging to species still living. These systems are grouped into three divisions, the oldest rocks being classed as Primary, the next as Secondary and the youngest set as Tertiary. Some geologists add Quaternary, to include very recent rocks and others

in course of formation, such, for instance, as the beach limestones of our West Indian islands.

The arrangement adopted by the English geologists has, with some modifications, been very largely accepted by geologists in general.

The following table of the English systems is taken from Marr's Introduction to Geology, explanations being here added after the names, as the most concise way of giving them:

SYSTEMS.

Tertiary	Recent	(Quaternary of some authors)
	Pleistocene	(Meaning most recent period)
	Pliocene	(Meaning more recent period)
	Miocene	(Meaning less recent period)
	Eocene	(Meaning Dawn of the recent period)
Secondary	Cretaceous	(Chalk system)
	Jurassic	(Named from the Jura Mountains)
	New Red Sandstone	
Primary	Carboniferous	(Coal-bearing system)
	Devonian	(From County Devon—Old Red Sandstone in North of England)
	Silurian	(From the Silures, a British Tribe formerly occupying South Wales)
	Ordovician	(From the Ordovices, a British Tribe formerly occupying Northwest Wales)
	Cambrian	(Cambria = Wales)
	Precambrian	(Before the Cambrian)

By way of further explanation, it may be added that the lower three systems of the Tertiary division were named by the great English geologist, Sir Charles Lyell, who called the lowest *Eocene* (dawn of the recent period) because it was found that only $3\frac{1}{2}$ per cent. of the fossil shells taken from it belonged to existing species. The proportion of existing species increased through the younger rocks, till in what Sir Charles called the Newer Pliocene *all the shells* belonged to existing species, the formation containing, however, the bones of certain quadrupeds which had become extinct. Later geologists have substituted the name Pleistocene for Newer Pliocene and have added Oligocene as a system to come between Eocene and Miocene, the name implying that the system contains the remains of a *few* recent species.

The reader who follows up the subject will find considerable differences in naming the systems as well as the great divisions, and some differences also in arrangement. Particularly he will find that the simple names of Primary, Secondary and Tertiary have been replaced by names of life-periods; and he will find that the New Red Sandstone has been divided into Trias (so named because including three different sets of strata) and Permian (so named from the province of Perm in Russia, where it is conspicuous) and that the Trias has been retained in the middle life-period, while the Permian is placed in the ancient life-period.

The following is the arrangement adopted by the United States Geological Survey:

PERIOD.

	Pleistocene	
Cenozoic	Neocene	Pliocene
(Recent life-period)	(new recent)	Miocene
	Eocene, including Oligocene	
Mesozoic	Cretaceous	Jurassic
(Middle life-period)	Juratrias	Triassic
	Carboniferous, including Permian	
Palæozoic	Devonian	
Ancient life-period	Silurian, including Ordovician	
	Cambrian	
	Algonkian	
	Archæan	

It will be seen that the above differs little from Dr. Marr's table. The term Precambrian, though here replaced by part of the Archæan (ancient) and the Algonkian (from the territory of the Algonquin Indians) is still sometimes used by the American geologists to include very ancient stratified rocks without fossils, and rocks such as those gneisses the original stratification of which is doubtful. The term "Recent" in Dr. Marr's table, omitted in the above, appears to be unnecessary, as the name of a system, when we have "Pleistocene."

It would far exceed the purpose of this chapter to try to describe, in however brief a fashion, the characteristic rocks and fossils of each of the above systems. By way of illustration, however, we may take the English Carboniferous system. As the name implies, it contains coal beds, but they are by no means all of the system; they form, indeed, a very small part of it. The most conspicuous rock of the lower part of the system is the Mountain Limestone, a hard blue-grey stone forming beds of two or three thousand feet in total thickness, some of them containing mostly shells, some mainly corals, others again full of stems of feather-stars (or sea-lilies), the encrinite limestone mentioned in the preceding chapter. Some shales (hardened clays) are found both above and below these limestones; then as we ascend, we come to great beds of coarse sandstones known as Mill-stone Grit, having a total thickness as great as that of the Mountain Limestone, and lastly we arrive at the set called the Coal Measures. These "Coal Measures" are made up of an immense thickness of shales and sandstones, clays and limestones, and contain much concretionary iron ore, the coal beds themselves, though by far the most important, forming only a small proportion of them. The coal beds, or seams, as they are commonly called, vary in thickness from 20 feet or more down to beds so thin as not to pay for the working. A coal bed commonly rests on a bed of clay called the *underclay* and is often covered by a bed of dark shale known as *roofing shale*. In the underclay the roots of the trees and smaller plants from which the coal was formed can sometimes be seen, and occasionally parts of the stems of the trees are found attached to the roots. These included

a few of the fir family, but most of the trees, as well as the smaller plants, belonged to the fern family and other flowerless plants. The shales which cover the coal frequently contain fragments of the same plants mixed with sea shells, which shows that the jungle in which the plants grew was overwhelmed by an invasion of the sea, the result presumably of the sinking of the land, a movement which must have taken place over and over again, with long periods of rest between, before the numerous beds of coal and the many intervening sandstones, clays and so on, of which the coal measures are made up, could have been produced.

In all ages of the earth's history the outline of the shore, the different depths in the adjoining sea, the courses of the great rivers, and the like, in short the physical geography of the time and the region, must have had a large share in determining the nature and extent of the respective deposits. Hence we find in the English Carboniferous system that its above named three divisions are differently developed in the different coal-fields. In the north the Mountain Limestones and the Mill-stone Grits are very largely developed, in South Wales the Coal Measures, which there attain a thickness of about 11,000 feet. The separation into "fields" is the result of movements which have taken place since the strata were deposited. The elevation of the Pennine range, for instance, has brought the Mountain Limestone to the top, the higher formations having been all swept away, but having been left on the west of the chain to form the coal-fields of Cumberland and Lancashire, and on the east to form those of Northumberland, Durham and Yorkshire. The above short sketch of the English Carboniferous system may serve to show what is meant by a geological system; but it should be added that the English coal-bearing strata, extensive as they are and important as they are to the country's prosperity, are yet only a small part of the world's wealth in this particular, for many extensive coal-fields are found in parts of Europe, North America, India, China, Australia and South Africa, the North American fields in particular being very large and far exceeding in area those of England.

In the Coal Measures the fossils naturally belong mainly to the vegetable kingdom, but there are also throughout the carboniferous system, as already mentioned, many shells, corals and encrinites; there are also forminiferous shells, insects, etc. Other systems are marked by special classes of fossils, for example, the older rocks contain crablike creatures called *trilobites,* their shells having *three* lobes. The Old Red Sandstone of the north of England contains many kinds of fossil fishes, while the rocks of Devon, belonging to the same period, consist mainly of slates and limestones and contain numerous corals. The Jurassic period is famous as the age of gigantic reptiles belonging to the lizard family. There were snake-like lizards, flying lizards with bat-like wings and fish-like lizards. The skeleton of one of these creatures now in the Museum of Natural History in New York measures 60 feet in length and 13 feet in height. In the time of the deposition of the Oolitic limestones, which form part of this system, there were also numerous sea creatures resembling

the nautilus in form, the shells of which are known as Ammonites. Some of these ammonites are of large size, and the writer remembers seeing near Portland, in Dorsetshire, many of them used along with the slabs of Oolite limestone to form stone fences between the fields.

The lower beds of the cretaceous system are not chalk, but sands and clays, and their fossils have considerable resemblance to those of the Jurassic period. The chalk beds themselves contain numerous shells and sea-eggs, but are chiefly characterized by being formed largely of foraminiferous shells and their fragments. The flints, which lie in sheets in the chalk and show as dotted lines in the cliffs, are concretions of silica, the source of which has been the silica extracted by marine creatures, such as sponges, from sea-water. This may be illustrated by the sponges of the present day, many of which contain flinty spikes such as may sometimes be seen in the sand from the sea bottom, say, for example, in Christiansted Harbour.

The fossils of the Tertiary Period show us the gradual approach to the life of the globe as it now exists—through numerous remains of both land and sea creatures and various plants. The appearance of man on the earth is a recent event, speaking in geological terms, but a very ancient one if we use the language of human history.

The above remarks may perhaps serve to give some faint idea of the great extent of the study opened up by the fossils which the various strata of the earth's crust have yielded and continue to yield; a study, the difficulty of which is increased by the many breaks that must necessarily come in the record and by the necessity of considering the climate and other conditions, not only of the various periods, but of the different places to which the fossils respectively belong. But we must now return to the main purpose of this section, namely, to answer the question, what are the ages of the rocks of St. Croix in relation to those of the earth's crust in general, where must our formations be entered in such tables as have been quoted? The answer must be left to the geologists, and we find that Professor Cleve, judging from the fossils collected here and in the neighbouring islands, puts down our Marl and Limestone Formation as of Miocene age and our Bluebeach Formation as Cretaceous; from which it will be seen that, notwithstanding the great periods of time that must have passed during the deposition, the subsequent movements and the sculpturing of our St Croix formations, they are comparatively young in the world's geological history, and we begin to have a dim perception of what a grand and marvellous work the creation of this earth of ours has been.

3.—History of the Rocks Subsequent to their Origin.

All the various changes in the character of the rocks which we found to have taken place in St. Croix, such as hardening, jointing, cleavage, formation of concretions, alteration by heat, and so on, are known among rocks elsewhere; but all rocks have not been submitted to these changes, a striking example of which is found in the London Clay, a deposit of about 500 feet in

thickness, above which, on some overlying gravels and clays, the city of London stands; this great deposit has remained a mere stiff clay, not entirely free, however, from changes, for layers of concretionary blocks of hydraulic limestone, the blocks known as septaria, have been formed in it.

The term "metamorphism" (change of form) is used to indicate all important changes that have taken place in rocks since their deposition; but the name *metamorphic rocks* is commonly restricted to clay-slates, marbles, gneiss, schists and other rocks that have been laid down as sediments and subsequently altered by heat. Some of these, as already noted, we have in the Danish West Indian Islands; others are not represented here. *Gneiss*, already mentioned under igneous rocks, is a very abundant rock, consisting of the same crystals as granite, but the materials showing signs of a stratified arrangement. In some masses of gneiss the tendency is so slight that geologists have supposed this peculiar arrangement to have resulted, like the cleavage in slates, from pressure; in other cases the linear arrangement is so conspicuous that the rock has been supposed to have been originally a stratified deposit from granite, which has been subsequently altered and hardened by heat. The *Schists* are rocks dividing naturally into irregular layers (the division is implied by the name) and are apparently altered sedimentary deposits derived from granite rocks. *Shales* are hardened muds, frequently showing a similar tendency to division.

In all parts of the world the sedimentary rocks are found to have undergone similar upliftings, bendings, denudations and depressions as we find recorded in the rocks of St. Croix. Even the summits of the highest mountains frequently show stratified rocks, just as do those of the lower hills and the plains. Evidence has been adduced to show that the lifting and lowering of certain parts of the earth have gone on, as in the geological past so also in historic times. Earthquakes, even in the present day, are sometimes attended with changes in the level of a country, and are probably the effects of such changes. This has been particularly the case with the shores of the South American countries bordering the Pacific; but the most striking illustration which the present writer has met with is recorded in the June number (1907) of the "Outlook," in an article headed "An Alaskan Wonderplace," by Oscar von Engeln. Here, the traveller tells of the grand mountains and glaciers in the vicinity of Yukutat Bay, and after describing the way in which a great glacier grinds down the rocks over which it passes, and how the material it removes is carried off by the stream issuing from beneath the foot of the glacier and by it is spread out over the adjoining plain, he continues thus:

"If the efforts which the glacial streams are making to counteract the destructive erosion of the ice are termed herculean, then titanic must be the word applied to the force which, in a single upthrust, lifted the land surface around Yukutat Bay, mountains and all, forty feet higher above the sea level than they had been previously. Never before in the history of geological science has a recent uplift of such magnitude been recorded. Moreover, the

evidence regarding the lesser ones is very obscure, so that we have here our first direct knowledge of tremendous crustal movements.

"The whole uplift took place during the latter half of September, 1899, being practically continuous during that time, with occasional sharp shocks; it caused great waves in the bay, probably as the water rushed out from it, for its bottom also was raised, as is proven by the appearance of new reefs and islands in its confines. Today one may walk for miles along its shores, over dry beaches, high above the reach of the highest storm wave, crunching under foot the yet undecomposed seaweed and the whitened barnacles clinging still to the rocks on which they once grew, and around which the surf once rolled continuously. The evidence of the uplift is complete. Old sea caves and wave-cut cliffs, areas where the plants have not yet had time to gain a foothold, all help to tell the story. If one has wondered how the sediments of old sea bottoms may form the summits of the highest mountains, here is an illustration of a force at work adequate to lift them to such a height.

"The two weeks during which this uplift occurred was a period of almost uninterrupted earthquakes in the Yukutat Bay vicinity. As reported by the missionary at the Indian Settlement at the mouth of the bay, and by prospectors encamped near by, some of the shocks were of great violence."

To the evidence of such examples may be added that of the raised beaches found in several parts of the world, which show that elevations have taken place in quite recent geological times.

The raised beaches of Norway are well-known examples, and a recent writer has given an account of several such beaches near Taltal, in the north of Chili, where he found three very distinct levels, namely, at fifteen feet, eighty feet and two hundred feet, respectively, above the present sea level, which were marked by the presence of boulders, well-preserved sea-shells, and caves of wave-erosion, pointing evidently to three successive upliftings of the coast at the place named.

We must remember, too, that an elevation sufficient to balance the wearing down of an island might take place without its being possible to observe it. Geological processes are for the most part extremely slow, we have seen that four centuries would probably be required to lower St. Croix by a single inch; where would the means be found to measure a rise of an inch at the end of that time, should it have taken place? If it were two inches, there would be a balance in favour of the island; it would be rising, but how could that be discovered?

The earlier geologists supposed that the processes by which the earth's crust has been built up had been formerly very active, but had in the present day nearly ceased. Sir Charles Lyell, in his "Principles of Geology," by calling attention to the nature of geological processes and by pointing out similar changes that are taking place at the present time, showed that this view was erroneous, but he probably went too far in the opposite direction in concluding that the story had been *always the same* since the dawn of geological

history. It is now generally admitted as probable, that the earth has cooled down from a molten state and that the crust has been pushed up in undulations here and there as the result of the contraction of the globe during its cooling, a contraction which, it is maintained, is still in progress. If this view is accepted, it seems necessary to admit that the earlier processes may have been very different, at all events in degree, from anything we now see.

On the other hand, it is quite certain that the greater part of the geological phenomena of the past may, as in the cases just quoted, be illustrated by the changes which we see to be taking place in our own day.

Age of the West Indian Volcanic Chain.

We may now return to the question which was left over from the last chapter, namely, the relation as to age between the two great axes of the West Indies.

For clearing up this question we must again look to the geologists. Prof. Cleve writes of a limestone deposit in St. Kitts as follows:

"At the foot of Mount Misery there is in Brimstone Hill a white limestone rock of considerable size, surrounded in all directions by loose volcanic rocks. I have not seen in it any trace of stratification. The rock has the appearance of chalk and contains many fossil shells and corals, the greater number in the form of casts. I have found about 43 different mollusca, all of species still living in the Caribbean Sea, except a single specimen of a *Modiolaria* closely related to a northern still living species. Among the fossil shells one of the most common is *Tellina Gruneri* Phil., also occurring in the miocene strata of Cuba and Porto Rico, and still living in the Caribbean Sea, but very rare. The greater number of still living species indicates the recent time at which the deposit was formed, and the formation may probably be determined as the newest pliocene or post-pliocene."

In the volcanic island of Basseterre, Guadaloupe, Professor Cleve says, some fossiliferous deposits have been found by *Mr. Payen*. "One of these deposits occurs at the height of 40 meters, about 50 meters from the shore, and the other, which rests upon horizontal beds of volcanic rocks, reaches the height of 100 meters and is 200 meters from the sea. They seem to belong to the same geological time as Brimstone Hill in St. Kitts."

The same geologist further writes of St. Eustatius: 'According to *Maclure* there is on the southeast slope of the cone a lime deposit of corals and shells, 'similar to those found in the sea.' He (Maclure) gives the following description: 'The whole of this marine deposition dips to the southwest at an angle of upwards of 45 degrees from the horizon, resting upon a bed of cinders, full of pumice and other volcanic rocks, and is immediately covered by a bed of madrepore, sand and cinders mixed together, with blocks of volcanic rocks so disseminated that there can be no doubt of the volcanic origin of the substance above and below the madrepore rock.'"

From the above quotations it is evident that the limestone rocks mentioned as so closely associated with the volcanoes have been put down at least during the eruptions, if not earlier, yet the evidence of the embedded fossils shows them to be "post-pliocene"; from which it may be inferred that the West Indian volcanoes are quite young in the world's geological history, and much younger than the formations which make up the east and west axis of these islands.

Questions of geological age must be left to the Palæontologists, yet it may be here pointed out that there must have been land along the north and south axis long before the existence of the present volcanoes. Dr. J. W. Spencer, who has of late paid a great deal of attention to the geology of the West Indian Islands, has concluded that in the volcanic islands, as well as in Antigua, there is an ancient base of trap rock, which he speaks of as "pre-tertiary trap." In Antigua it is between this trap, exposed along the southwest coast, and the limestones of the northeast that the strata containing silicified fresh water shells and silicified woods occur. The wood fossils prove that there must have been land there at the time they were deposited, and it was this land which afterwards sank under the sea and received upon it the limestone beds of the northeast. In Barbadoes also evidence is found of an ancient land. The geology of that island was described by Sir Robert Schomburgh in his History of Barbadoes, published in 1848, and it has been more fully described a few years ago by the well-known English geologist Jukes-Browne and Professor Harrison. The larger part of the island is covered with a coral formation, all of which the latter writers consider to be very recent. Dr. J. W. Spencer believes, however, that there are remains of an older limestone formation than the recent coral rocks. However this may be, the whole mass of limestones rests on an older formation, which has been reached by borings through the limestone in several places, and which appears on the surface over a considerable area on the east coast, an area which has been so variously carved out by the streams into hill and dale that it is locally known as Scotland. The "Scotland formation" consists mainly of a great thickness of sands and sandy clays, some of them hardened into stone, others having very little coherence. Sir Robert Schomburgh calls attention to the shore sand in that district, pointing out that it is quite unlike the sand on other parts of the coast, being siliceous while the other is shelly; it is, in fact, the kind of sand which is mentioned in Part 1 of this chapter as derived ultimately from granite. Over the "Scotland formation" is another coming between it and the coral limestone, and known as the "Oceanic formation." Mr. Jukes-Browne and Professor Harrison give a full account of this remarkable formation, which is made up of over 300 feet of deep-sea deposits, some of the layers being chalky and abounding in foraminiferous shells, others consisting of fine clays of varying colours and siliceous earth, the latter, with a thickness of 130 feet, being almost entirely composed of the microscopic flinty skeletons (whole and fragmentary) of creatures known as Radiolaria, and hence called Radiolarian earth, or, on account of its

fineness, Radiolarian ooze. The Radiolaria are near cousins of the Foraminifera, but their coverings are not made from lime, like those of the latter, but from the clearest silex; and when they are seen through the microscope, this quality, along with their greatly varied and beautiful forms, make them very attractive objects. The Radiolarian shells of the present day are found in water 10,000 feet or more in depth; hence it has been argued that the Scotland beds, which belonged to shallow seas, must have sunk to at least that depth. How long did they remain there to take the considerable thickness of those fine-grained beds on their surface? It is impossible to answer, but when we think of the fine rain of these microscopic skeletons descending on the ocean floor, we must conclude that an immense time must have elapsed before it could have produced such a thickness of strata as the later elevation has made visible. The Scotland beds contain a substance which Sir Robert Schomburgh describes as coal. Mr. Jukes-Browne speaks only of the "black bituminous clays" of the Scotland formation. Locally the product is known as *manjack*. Petroleum is obtained from the same formation. The presence of such beds, however they may be described, is sufficient to prove the existence of an abundant vegetation in that ancient land, just as the agatized woods prove it for Antigua.

Dr. Spencer says that the age of the Scotland beds has not been settled, but he thinks from their very great total thickness that they must be dated probably as far back as the Eocene time. It is worth noting that these beds were very much disturbed before they went down into the sea, for they dip in various ways at different places, yet were planed down before sinking, so that the "oceanic beds" rest upon their upturned edges, or, in geological language, they rest unconformably upon them. The uppermost bed of the oceanic series is a twenty-five feet of thickness of "grey volcanic mudstones," which the authors consider to have been probably formed from volcanic dust drifted from distant volcanoes, as there is no sign of any volcanic outburst on Barbadoes. It is interesting to note that radiolarian earth is also found in Trinidad, Cuba, Hayti and Jamaica.

From the above facts and expert opinions it seems likely that there was an old north and south axis long before the present volcanoes existed, and possibly as old as our east and west axis.

While the settlement of questions of age must be left, as already said, to the palæontologists, the geological facts available are very instructive, for we see that these other islands have, like our own, accumulated the materials of their construction from different sources, and have been subjected to elevations and depressions similar to those which we have seen to have taken place in our own island.

CHAPTER XII.

Conclusion.

While it seems desirable, in entering on the study of the geological formations of our island, to begin with the younger set of rocks and trace the story backwards, it may be instructive, in summarizing the results of our observations, to take the opposite course, and, as far as possible, note the leading events and conditions in their natural sequence.

As a preliminary, we must remember that the crystalline structure prevalent in our older formation has been induced in the strata since the materials of which they are composed were deposited, and similarly that the dykes of igneous rock which we find cutting them through have been intruded, so that in the first instance we have to confine our thoughts simply to their deposition.

To begin with, we have, then, to picture to ourselves as existing here long ages ago, perhaps about the time that the chalk of Europe was being deposited, a sea bottom to receive the beds and an adjacent land from which the material to form them was obtained. That the land was near by is shown by the occurrence of conglomerates, and in a striking way by the layer of well water-worn pebbles previously mentioned as seen in Buck Island, a layer which must either have formed a part of a shingly beach or have been put down in shallow water not far from it. The proximity of the land for at least the greater part of the time during which the materials were being deposited, is further shown by the frequency of the occurrence of ribbon-like markings in the stone, markings which indicate successive deposits of thin layers and point to oft repeated invasions of sediment from the shore, and it is also shown by the very numerous beds that have reached thicknesses of a few inches only and may well have been put down not far from the land. The thick beds of fine-grained slate, such as those we see near Mt. Victory, must have been formed farther out, in places to which the currents could bear the finest drift only; yet a distance of one or two miles would, in most cases, be sufficient to secure the needful conditions, though it may, of course, have been very much greater.

The conception of another land still farther back in time, a land which we have pictured as being destroyed in the making of the older portion of our island, arouses our interest. What sort of a land was it? We see in our own rocks part at least of the stuff of which it was built, and we perceive that it had a sea beach, in some parts bordering shallow seas, and it had streams that ran down from its hills and valleys and across its plains. Was it a volcanic land? The finding in the strata of St. Thomas of scoriaceous fragments, as described by Prof. Cleve, proves that it was, and it may be that the volcanoes furnished a good deal of the material from which our rocks were formed. On the other hand, the volcanic outbursts may have taken place through non-volcanic strata, and the latter may have supplied the greater part of the

material in question. At all events, the strata we now have were laid down at the sea bottom, and they reached a thickness so great that we must suppose that the land from which they were being formed was sinking while the accumulation was in progress.

What depth of material was lodged in that ancient sea? If we could get any reliable approximation to the total thickness of the beds in the older formation, as we can do for the marl and limestone formation, it would be easy to answer the question, so far, at least, as regards the part now remaining; but we do not see the base on which the rocks rest, and the strata, as we have seen, have been very much disturbed. Professor Cleve, writing of St. Thomas, says: "The blue-beach seems to me to be at least 2,000 metres (about 6,500 feet) thick." This probably excludes the felsite of the south and the clay-slates of the north, and if so the total thickness of the St. Thomas strata would presumably be much greater than that stated. If in St. Croix we take the distance between Lower Concordia and Mount Washington, across the southern side of the northwestern anticlinal and assume a high angle of dip throughout, we should get a thickness of at least 12,000 feet; but on the one hand we cannot be sure that at Concordia we have arrived at the southern limit of the southerly dipping beds, neither do we know the depth to which the strata reach at the axis of the anticlinal, and on the other hand we cannot be sure of the absence of minor folds, the presence of which might considerably reduce the estimate. It seems, however, to be safe to conclude that the total thickness of the clay formation is very great and is to be reckoned by thousands of feet instead of by hundreds as in the limestone formation. While this great mass of clays was being piled up, the sea added on its own account occasional small contributions of limestone.

After the deposition of the great thickness of clays and its few associated limestones, the accumulated beds were forced up above the sea and compressed into the numerous parallel ridges and hollows which we have found them now to reveal, and this process probably extended through a very long period of time. Other processes, most likely at the same time, and perhaps from the same causes, went on, the strata being to a great extent made crystalline and otherwise altered to the forms in which we now see them. Dykes and masses of igneous rocks were, probably about the same time, forced into them; but that this invasion of molten matter ever went so far as to produce eruptions ending in the formation of volcanoes there appears to be no evidence to show.

Thus a new land was formed out of the waste of the old; but no sooner was it pushed above the sea level than the sea began to attack its edges, and the atmosphere and the rains began to lower its surface; and continuing through long ages, these forces wore down the slopes of its ridges, first into hill and dale, and then, in part at least, into plains, just as they had done with the ancestral land.

Then comes another swing of the pendulum, the worn down land begins to subside, and on its plains, now under the sea, great thicknesses of sea sand,

with corals and other remains of sea creatures, are slowly accumulated, while occasional deposits are brought down by streams from the remainder of the land not yet under the water and are mingled with the shell sand or are laid down as small beds of hard sand and gravel. Whether the whole of the land ultimately went down under the water there is no means of ascertaining; neither is it possible to say to what depth it sank. Down to the present time no oceanic deposits, as in the case of Barbadoes, have been discovered in St. Croix, and indeed it seems likely, from the frequent occurrence of pebbles from the older rocks in the marl formation, that the latter was put down during a period of slow subsidence. It does not seem likely, therefore, that an oceanic deposit, if it existed here at all, would be found, as in Barbadoes, between the limestones and the older rocks. However that may be, the subsidence must have been a long one to allow of the deposition of the 600 feet of limestones and marls which we now see, to say nothing of that large part of the original deposit which must have since been swept away.

After the long interval of subsidence comes another period of lifting when the remnants of the second land, bearing on its surface the great accumulation of limestones, is once more forced above the waves, this time, however, with much less disturbance of its strata than in the older uplifting movement, and without intrusions of molten rock, or at all events with none that were powerful enough to penetrate the limestones. Just as we asked in regard to the sinking of the land, how deep it went under the ocean, so we may now ask about the lifting, how high the land was raised. In an earlier chapter it was mentioned that naturalists had concluded from the plants and land-shells of the West Indian islands that they had at one time formed continuous land, in which case the lift we are considering was probably very great. Dr. W. J. Spencer, the American geologist already quoted, has arrived at the same conclusion on geological grounds. He says that the soundings off the coasts of the Atlantic States show that the courses of the rivers flowing from the mountains over the present coast plain, can be traced over the sea bottom far out into the ocean to depths of thousands of feet, from which he concludes that the land off the coast is a sunken plain, and he sees reason to believe that the sinking has extended through the Bahamas and the Caribbean Islands to the South American coast. He believes that there is evidence to show that there was a large plateau joining the two continents and having its highest line towards the east while its drainage ran west into the Caribbean Sea. Hence he regards the channels between the islands as former valleys, and the islands themselves as remnants of a mountain chain which had been intersected by the streams. He writes of "The West Indian bridge between North and South America" and speaks of the present great depth of the channels as a "yardstick" to measure the former heights of the mountains, which he estimates to have been 10,000 to 12,000 feet or perhaps in some cases even 14,000 feet. These great elevations he believes were reached in Pliocene times, after a previous sinking of the land subsequent to the deposition of the

Miocene limestones. Dr. Spencer regards these great earth movements as quite different from the mountain-building thrusts, and if his views are correct, it is likely that the land here stood much higher at the end of the period of lifting than we now see it.

Whether this were so or not, we see a third land appear to view, not to remain intact, however, but to be dealt with just as its predecessors had been dealt with, that is to say, to have its raw material broken up by the air and sculptured by the streams into beautiful forms, and its soil prepared and kept fit for the nourishment of the multitude of plants that come to adorn its surface. On this land it is that we live, and most of us feel that it is indeed a fair and a pleasant land.

Some years ago, the writer, while driving along one of our country roads with a young companion, pointed out a few layers of limestone showing in the roadside bank, and remarked that we could there find a lesson about the way in which the island had been built up. "But I thought the world was as God made it," was the reply, to which was answered, "Certainly, you can still think so, but that need not prevent your learning something of *the way* in which it was made." Fortunately, no special knowledge is needed to see that in this beautiful island of St. Croix we have a goodly heritage, and to feel the gratitude that naturally arises from the sense of the greatness of the gift. For some of us the ground for gratitude is greatly increased by the added pleasure of knowing something, in however meagre and dim a fashion, of the truly wonderful processes by which this goodly heritage of ours has been created.

NOTES.

On Finding the Anticlinal Axis of the Northwest.

It has been noted (page 45) that an anticlinal axis divides the rocks of the Northwestern Hills which dip to the south or thereabout from the rocks that dip to east-northeast or thereabout, and that such axis is found to lie about west-northwest and east-southeast.

In order to be able to lay down this line we must traverse the roads passing through the hills and note the dip of the stratified rocks wherever we can find them.

In this examination it will be advisable to commence with the road passing from the estate *Little La Grange*, in the valley, to the estate *Punch* on the top of the hill.

The diagram shows the sequence of the different dips met with along this road. The measurements between the successive points are not exact, having merely been stepped out; but they may be of some use to a reader who may care to follow up the observations. It may, in the first place, be noted that near Punch the southerly dips that have been met with during the ascent change over to northeast. Next we may note that at several points the strata are vertical or nearly so, while at other points they pass over to northerly dips. This need not confuse us, for we have already learned that rocks, which on the whole dip to the south, may in some places be vertical and in others be even pushed over so as to get a reversed dip. The great value of the observation in this case is that it enables us, when we pass to the seashore, to see that we may properly retain small areas of northerly dip in the large area of southerly dips, seeing in the rocks of such smaller areas examples of reversion of dip on a considerable scale, and not change from one larger area to another.

Following the coast from Frederiksted northwards we first come to the cliff at Spratt Hall, where we find slaty rocks in regular layers dipping to north at about 50. This is so great an amount of reversion that we might be inclined to think that we must have come to the north slope of the anticlinal if we did not observe that the dip lacks the more marked easterly tendency which we find farther on when we actually come to the great northeast slope of the anticlinal. At Butler's Bay, farther north along the shore, we find a like dip as to direction; but the rocks have not been thrust so far over, the dip being 75 degrees to north-by-east. Continuing northward, we come to the real change when we arrive at the estate Northside, where we find in a cutting a dip of from 30 to 40 degrees to east-by-north. Our having now passed into the area of the northeast dips is confirmed when we come into Ham's Bay, where we meet

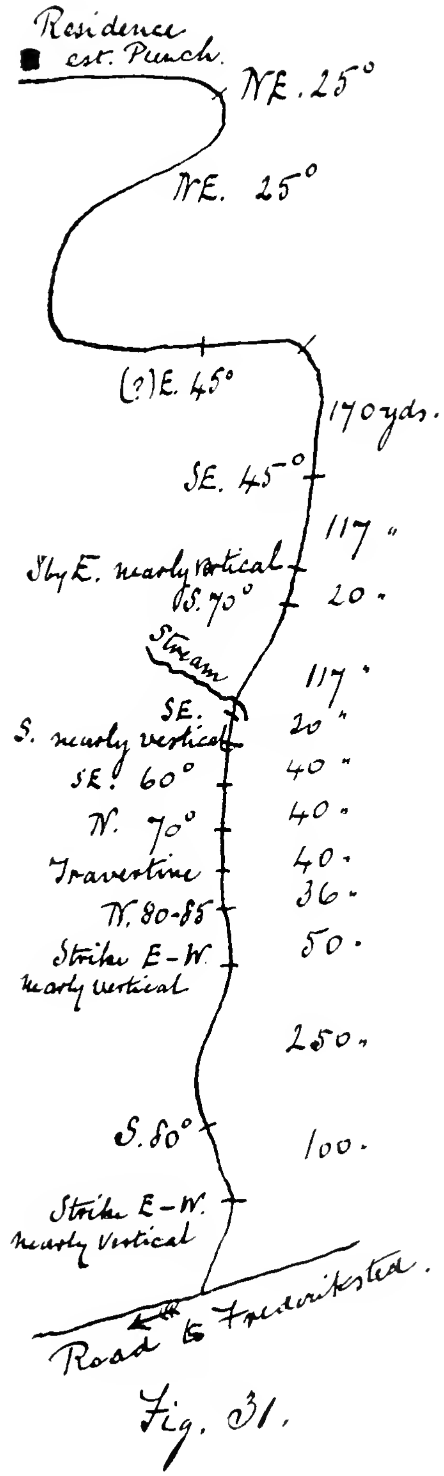


Fig. 31.

with a dip to northeast at about 50 degrees, while at the Bluff we find highly contorted strata, the dip varying greatly, but being on the average to a little south of east. So far, then, we have discovered that the dividing line berween the two sets of dips must begin on the coast, between the estate *Butler's Bay* and the estate *North Side*, and must also pass just to the south of the buildings at the estate *Punch*. To fill up the interval as far as possible, we traverse the road from the estate *Sprat Hall* up the valley known as the Creque's to the estate *Mt. Victory*. On the estate Sprat Hall (the mill-tower lying north-northwest) we find thin beds of indurated clay rocks exposed, some of them decomposing to a white clay, the dip being about 70 or 80 degrees to north by-east. After this the debris brought down by the stream which runs along the bottom of the valley, hides the rocks until we come nearly under Mt. Washington, where we find exposures of layers of indurated clay and slaty rocks, with dips varying in direction from east to east-northeast, and in amount from about 40 to 50 degrees.

Hence it appears that we have again crossed the line of division or, in other words, the anticlinal axis, and just in the place where our previous observations had led us to expect it. Continuing along the same line of road eastwards we find repeated evidence that we are traversing the area of northeasterly dips. At the small waterfall, on the way up the valley, we find the dip east-by-north at 35 to 40 degrees. The rocks are mostly slates, some of them thin-bedded and others two feet or more in thickness. The cleavage appears to lie about northwest and southeast. Farther on, near Mt. Victory, slaty beds are shown, dipping to east-northeast at about 45 degrees. Crossing Annaly Hill, at the top of which, near the mill, there are evidences of strata dipping about east, we come, near its foot, to slaty rocks in slabs with a dip of about 25 degrees to north-northeast, which is exceptionally far round to the north and appears to be only a local departure from the usual direction, for a little farther on, where the road coming down from Annaly joins the road to Montpellier, we find a large gravel pit showing dips at about 30 or 40 degrees to east-northeast. Following the road past Montpellier, we find at Two Friends hill layers of slaty rocks dipping to east-northeast at about 45 degrees

Lower down the valley (near the old mill at Springfield) there are several exhibitions of the rocks by the roadside, mostly slaty, with a rough cleavage about northwest and southeast, the dip being east-northeast at about 50 degrees. Lastly, in the natural cut made in the steep hillside by the stream northwest of Grove place there are traces of stratification, the dip being east-by-north at about 45 degrees.

After emerging at Grove Place into the great plain, the observations cannot be continued to the southeast, the whole plain being covered by debris from the hills, but they can be continued eastwards in the hill at Upper Love village, where two gravel pits reveal the stratification, that on the west side showing a few strata dipping east at about 70 degrees, that on the east side showing a like dip at about 60 degrees.

We may further amplify our observations by now returning to the western side of the hilly district of the Northwest and traversing the road that leads past the estates Prosperity, Jolly Hill, and Orange Grove, and then enters the road just examined. Here we find a beautiful exhibition of the rocks of the district where, at Jolly Hill, the stream crosses the road and runs over a set of intensely hard blue-beach rocks, in which the strata are clearly marked. The dip here is south-southeast at a very high angle (about 70 degrees) Farther along the road, before reaching Orange Grove village, we find, in a road cutting against the hillside, stratified rocks dipping to northeast at about 45 degrees. Here again it is plain that we have passed out of the area of *southerly dips* into the area of *northeasterly dips*; in other words, we have once more passed the anticlinal axis, which consequently we are now able to continue from near Punch to a point in the road between Jolly Hill and Orange Grove.

To establish the fact that the southern dips prevail through the southwestern part of the Northwest Hills (just as we have shown that northeast dips prevail through the northeastern part), we can add to the observations already made by following the roads leading from the southern plain up the several valleys which come down the south slope of the hills. There are three such roads, the middle one showing on the edge of the stream some plainly stratified rocks dipping to a little east of south at a high angle and to the south of that another outcrop on the east side of the road showing a high dip to north. A careful search in the other two valleys would perhaps give similar evidence, though such has not been seen by the present writer.

NOTES.

On Finding the Anticlinal and Synclinal Axes of the Eastern Triangle.

On page 49 it was shown that on examining the rocks along the cleft called "Spring Gut," which cuts through the Christiansted group of hills from North to South, a change in the dip was found to take place towards the southern end of the valley where the dip passes from about southwest to east-by-north, and that at Longford, in the plain below, the dip was found to be east-northeast. First assuming that we have here, at the change of dip, a point in a synclinal axis, and that such axis has the same direction as the similar axis in the northwestern oblong, we run out the line, in both directions, and we shall find that, with a very slight modification, it will, in both directions, come out at places where the dip changes from the one class to the other; that is to say, from dips looking towards the south quadrant to dips looking towards the northeast quadrant. Towards the northwest, along the line, the change takes place close to Beeston Hill, where the main road some years ago showed a section roughly sketched in the diagram (Fig. 32). When this diagram was drawn and the following notes made, the writer had no idea of the true significance of the change of dip at this place, but supposed it be merely a local reversion. It was not till long afterwards that he found that the new dip extended over a considerable strip of country southwards and indicated the presence of a synclinal axis at the place where the change takes place. The notes read thus: "In repairing the road at 'a' and 'b' in the plan the bank has been cut into by the hoe and a clean surface exposed at about six feet below the surface of the soil at the top of the bank. The cut surface shows the usual thin bands of indurated clay rocks, some of dark colour, but most of various light brown shades. At 'a' they dip south, at 'b' north. The decomposition is such that the greater part may be called clay, but some beds, though cracked into small fragments, retain a certain degree of hardness in those fragments, The whole length has been quite smoothly cut with the hoe. On the opposite side of the road the rock also shows strata dipping northwards."

Later observation showed that the "northward" dip was about north-northeast, or north-by-east, and, as already noted, such dips extend over a wide strip of country stretching southwards.

While on the south side of this change at Beeston Hill the dips are all to the north, on the other, namely, towards Christiansted, they are all to southwest. Hence it is clear we have here come upon a synclinal axis, and it is the same as was iddicated by the change of dip in the "Spring Gut" Valley.

Returning now to the middle of our synclinal line and following it to the southeast we find that it separates the rocks at Fareham Point, which dip to northeast, from those at Petronella, which dip to southeast-by-south. Thus the northern boundary of the strip of country where the strata have a northeasterly dip is apparently settled. Proceeding next to find its southern boundary, we first follow the south coast from Fareham westwards to find out where the dip changes; and we find south of the old mill at Fareham some stratified rocks of indurated clay dipping east-northeast at about 50 degrees. Hence we are still in the same strip of northeasterly dipping rocks. Farther west, however, we come, on reaching the point at the east end of Springs Bay, to a set of clearly stratified indurated clay rocks dipping in quite a different direction, namely, to south-by-east, at about 45 degrees. Hence we appear to have passed once more into a district of southerly dips. This discovery is borne out when we follow the road from Longford westwards and find close to the new bridge at Cornhill some well-defined strata dipping at about 60 degrees to south-south-

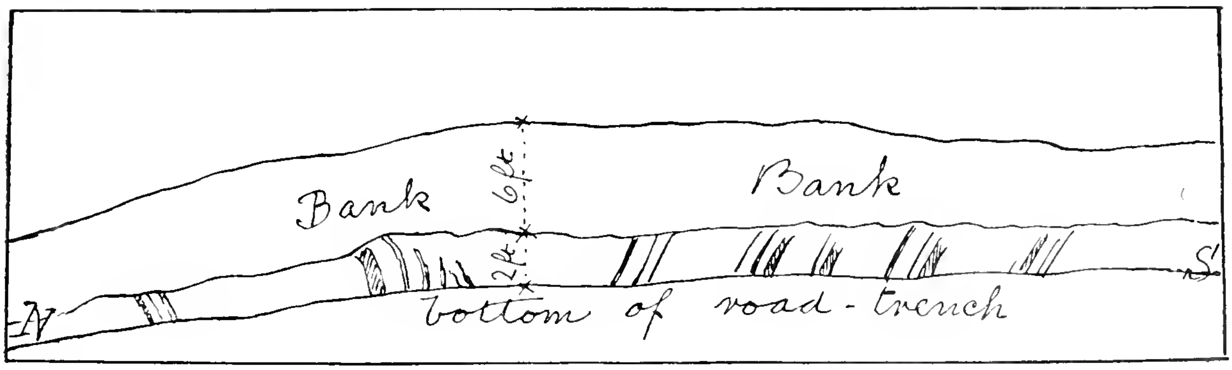


Fig. 32.

west. Hence we see that the line separating the northeast dips from the southern dips passes from east of Springs Point, just south of Longford and north of Cornhill Bridge. We are able to continue it still farther to the northwest by noting that an old quarry (gravel pit) on the main road going south past Catherine's Rest (Longford's new chimney lies southeast-by-east) shows rock layers with a distinct dip to south-southwest at about 45 degrees, while another gravel pit to the north of that, namely, at the turning in the road, shows traces of a dip to north-northeast at about 30 degrees We can therefore continue the line northwest, passing between these two quarries.

Thus we have traced out a line which separates northeastern dips from southern dips, and we find the result confirmed by the dips at Waiter's Point and a point to the east of it. At the latter point it is true that two dips are found, some of the rocks dipping to northeast-by-east, some southwest-by-west, the alternations taking place within an interval of only a few yards. These changes to northeast appear, however, to be mere reversions of the dip, which all the facts show should be counted with the south quadrant class. Hence we have laid down a line separating the areas of different dips, and this line is of course an *anticlinal* axis, just as the line to the north of it is a *synclinal* axis.

When we now go back a little in our story, and compare the dips on either side of the above traced anticlinal axis, the first which we have discovered in the eastern triangle, with those on either side of the anticlinal axis of the Western Oblong, we notice that while an examination of the southeast part of the line, say from Longford to the shore, shows us that the dips bear a similar relation to the present axis as do those of the Northwest anticlinal to their axis, that is to say, they have on both sides an inclination to the east, an examination of the other part, that is the northwest part, of the line, shows dips tending rather in the other direction, namely, north-northeast or even north-by-east on the north side of the anticlinal and south-southwest or even southwest on the south side. Compare, for example, the pair of dips at Longford and Springs or Fareham and Springs, towards the southeast end, with the pair at Bugby Hole and Corn Hill bridge or Catherine's Rest and Waiter's Point towards the northwest end of the line.

If now the tendency to the east on either side of the southeastern part of the anticlinal is caused, as suggested in regard to a like arrangement in the Western Oblong, by a cross elevation tilting the rocks towards the east, may not the opposite be the case in the northwest part of the anticlinal? In other words, may there not be a cross axis of elevation which separates these two diverging tendencies, tilting the rocks on its east side towards the east and on its west side towards the west? And if so, where is this axis? It may not be possible to lay it down with any exactness; but when we see that the rocks in Christiansted and on the western boundary of the town dip mostly to west of south, while those immediately to the east of the town dip to south and farther out dip to south-by-east, we may consider that we have found further evidence strengthening the conclusion derived from the arrangement of the rocks on the south side of the hills. It seems then to be probable that a cross axis of elevation in the ancient rocks followed about the same line as is now taken by the remarkable cleft through the Christiansted Hills, a cleft which perhaps indicates a like cross elevation on a smaller scale in more recent geological times.

If we now pass northwards over the Christiansted rocks, with their southerly dips, we find the same dips prevailing till we arrive at the Point at the entrance to the harbour, on which stands the lighthouse and the ruins of Fort Augusta. Here the strata are well marked, and although somewhat contorted, they dip to about southeast. Not far east of the point the dip changes again, this time to northeast, and it is evident that we have arrived at a second anticlinal axis, the crest of a second fold in the strata. Following up this northeasterly dip we find that it extends along the north shore to a point opposite the islet called Green Cay, and is found in a few strata towards the south end of that islet, and that it stretches southeast in a band across St. Croix, similar dips being found at Boetzberg, at Lowry Hill, at Mt. Fancy and "Madame Carty" on the south coast.

Beyond this strip northeastwards we find another, in which the dips are once more to southerly and southwesterly points, which may be traced from the north coast past Green Cay and East Hill School house, and appears to be represented on the south shore by the rocks at the west end of "Turner's Hole."

This narrow strip is succeeded by another band in which northeasterly dips once more prevail, and are shown in the rocks of the north shore from Coakley Bay to east of Solitude Point. In the last named point the strata are well marked and appear along the beach, the dip being about 60 degrees to northeast by east. In one or two places the beds are vertical and even reversed; but on the whole the dip is as stated.

Following this strip with northeasterly dips comes another with dips to southwest, changing over, as we proceed eastwards, to southeast; the southwest dips being found in all the points from "Solitude" eastwards to the west end of Tague Bay, the southeast dips in some rocks near the east end of Tague Bay.

The lines laid down in the map indicate the various anticlinal and synclinal axes as thus ascertained, and it appears to be certain that the same great force which has produced the anticlinal axis and the synclinal axis of the northwest has also pushed up the strata into numerous great ridges in the eastern part of our island.